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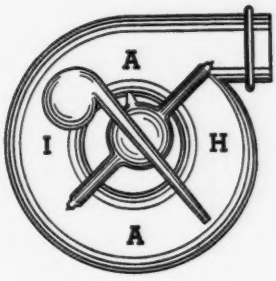

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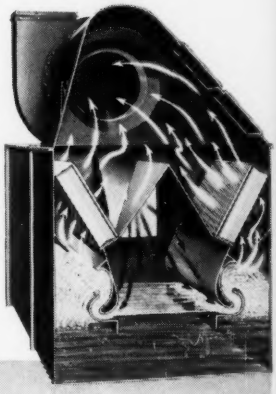

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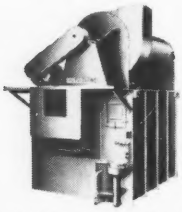

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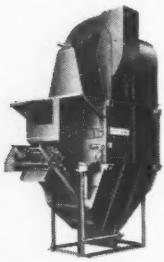

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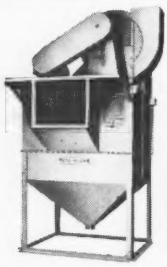

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An Improved Method for

Beryllium Analysis

in Biological and Related Materials

By J. CHOLAK and D. M. HUBBARD
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SPECTROGRAPHIC METHODS of high sensitivity for the determination of beryllium were described by the authors in 1948.[1,2] The more sensitive method employed the cathode layer technique for excitation, with which it was possible to detect as little as 0.0025 microgram per milliliter of prepared solution.[2] This method required the isolation of beryllium in a solution of small volume, which was accomplished by concentration, after first precipitating the beryllium as the hydroxide or phosphate from solutions of the ashed material. It was shown that this method of isolation was complete for the small quantities of beryllium encountered.[2] The use of this isolation technique was limited, however, to relatively small samples not exceeding 25 grams of tissue or 50-75 milliliters of urine. With larger samples difficulties were encountered due to the variable quantities of salts which were precipitated with the beryllium. Increased quantities of salts placed on the arc decreased the sensitivity of the spectrographic detection of beryllium. The effect of total ion concentration in the arc on sensitivity is illustrated in Fig. 1. The illustration shows the decrease in intensity of the beryllium line (2348.6 A) which is obtained when the quantity of total salt on the arc is varied from 3 milligrams to 50 milligrams. The maximum sensitivity is obtained with 3 milligrams of material on the arc, confirming the findings of Mannkopff and Peters for the cathode layer method of excitation.[5] The importance of controlling the total salt composition of the material to be arced is evident.

In spite of this difficulty the sensitivity and specificity of the spectrographic detection are superior to those associated with the use of chemical methods. The inability to work with samples of urine greater than 50-75 milliliters in volume limited the certain sensitivity of detection in this material to 0.05 microgram per liter of urine. This left a range of uncertainty which needed correction and, therefore, a number of methods for isolating and concentrating beryllium from large amounts of tissue and particularly from large volumes of urine were investigated. The method of Klemperer and Martin,[4] in which calcium was removed by precipitation in an alcohol-sulfuric acid medium was not completely satisfactory in our hands.

Combes[3] and later Parsons[6] prepared beryllium acetylacetonate by the action of acetylacetone on a solution of beryllium hydroxide in acetic acid. The beryllium acetylacetonate was so pure that this salt was used by Parsons[6] as a basis for the determination of the atomic weight of beryllium. More recently Toribara and Chen[7] produced the acetylacetonate and extracted it free from calcium with benzene at a pH between four and five. Treatment of the benzene extract with hydrochloric

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Fig. 1.
The effect of total ion concentration in the arc on the sensitivity of the spectrographic detection of beryllium.

acid converted the beryllium complex to its chloride. Other interfering cations were removed before the acetylacetone treatment by electrodeposition with a mercury cathode. Toribara and Chen worked with the radioisotope Be^7 and by utilizing carrier-free isotope claimed ability to detect less than 10^{-4} micrograms of beryllium. However, the least quantity of beryllium listed in their tables of recovery was 1.3 micrograms of beryllium.

Our problem was to isolate the beryllium as free from extraneous ions as possible in order to control the composition of the final solution used for spectrography. This was accomplished primarily by the formation of beryllium acetylacetonate and its subsequent removal from the solution. Our present method, therefore, permits the detection of as little as 0.01 microgram of beryllium per liter of urine when using 250 milliliter samples. The sensitivity of detection can be increased further when larger volumes of urine are available. The following paragraphs describe the improvements and give recovery data as well as some comparisons between our present and earlier methods.

Preparation of Samples

THE USE of larger samples (especially of urine) made wet digestion techniques impractical and inconvenient whereas the method of dry ashing was much more practical. In our original work, losses which were attributed to volatility, possibly that of beryllium chloride, were shown to occur during dry ashing.[1] Subsequently both Klemperer and Martin[4] and Toribara and Chen[7] used dry ashing methods without losses. The latter showed that losses could be prevented by treating the ashed material with sulfuric acid. This conclusion was verified by us in the preparation of large samples of urine or tissues.

Samples of urine are transferred to glazed silica dishes of suitable size and are evaporated to dryness after the addition of 10 ml. of concentrated nitric acid for each 100 ml. of urine. Tissue samples may be handled similarly or the initial addition of acid may be omitted. After the samples are thoroughly dried they undergo a charring treatment by placing them on an adjustable Lindberg hot plate. Charring is continued until all volatile material is driven off and ashing is then completed in a muffle furnace at 500° C. (Small amounts of carbon may be destroyed by retreating the ash with a small quantity of concentrated nitric acid, evaporating to dryness and again placing the dish in the muffle furnace at 500° C.) To the ashed sample, 1 ml. of concentrated sulfuric acid is added for each 100 ml. of sample employed (or each 25 grams of tissue) followed by 10 ml. of concentrated nitric acid.

Small samples (less than 100 ml. of urine or 25 grams or less of tissue) can also be prepared by the method of wet ashing described earlier.[1,2] In this case the excess sulfuric acid is concentrated to the proper volume (1 ml.) by fuming off as SO_3 and the sample is then treated with nitric acid as described above.

Isolation of Beryllium

THE SILICA dish is then placed on a hot plate and the contents are stirred with a glass rod to effect solution of all soluble salts. Heating and stirring are continued until all of the nitric acid is evolved (fumes of SO_3). After cooling, 20 ml. of distilled water are added, and upon reheating and stirring all soluble salts go into solution and excess calcium precipitates as the sulfate. The sample is transferred quantitatively to a 50 ml. centrifuge tube and centrifuged for five minutes. The supernatant liquid is then poured into a clean 100 ml. pyrex beaker, the precipitate is resuspended in approximately 2 ml. of distilled water,

and the mixture is filtered through two thicknesses of Whatman No. 2 filter paper (4.25 cm. in diameter) or the supernatant liquid may be saved after recentrifuging. The filtrate is caught in a 15 ml. cone tipped centrifuge tube inserted within a 250 ml. suction filter flask. The 50 ml. centrifuge tube is then rinsed with 2-4 ml. of distilled water which is also used to wash the paper containing the calcium sulfate precipitate. The combined filtrates, or the supernatant liquids from the separate centrifuging operations, are added to the liquid in the 100 ml. beaker as described above.

Ordinarily iron need not be removed from the solution even when dealing with urine samples as large as 500 ml., but it is removed from samples of tissue (particularly blood) by the popular mercury cathode method of separation or by the cupferron method.[1,2]

To the solution of approximately 30 ml., following removal of calcium and iron (if found necessary), are added five drops of glacial acetic acid and one drop of 0.1% aqueous solution of methyl orange. Concentrated ammonium hydroxide is then added drop by drop with stirring to obtain a pH of approximately 4.5. The contents of the beaker are removed quantitatively to a clean 150 ml. Squibb separatory funnel, 4 ml. of acetylacetone are added, and the mixture is stirred for five minutes at approximately 1000 R.P.M., using an electric stirrer equipped with a glass stirring rod.[7] The next step is the addition of 20 ml. of thiophene-free benzene, and stirring is again continued for 15 minutes, after which the aqueous layer is discarded. Finally 15 ml. of 5 N hydrochloric acid are added, and the mixture is stirred again for 15 minutes. The hydrochloric acid solution containing the beryllium is now removed to a clean 50 ml. cone tipped centrifuge tube containing 0.5, 1 or more ml. (depending on the expected beryllium content) of the spectroscopic buffer and prepared for spectrographic analysis by the methods described earlier.[1,2]

Discussion

ACETYLACETONE isolates beryllium quantitatively, as was indicated by Toribara and Chen.[7] Table I gives recoveries of traces of beryllium when added to 100 ml. volumes of normal urine. These recoveries are acceptable for the ranges tested. These data prove that as little as 0.0025 microgram of beryllium can be isolated. This sensitivity would permit the detection of a concentration as low as 0.025 microgram of beryllium per liter of urine in a sample of 100 ml. but since the size of the sample is not a limiting factor, with the present method the sensitivity of detection can be extended to a fraction of the above value when larger samples are available.

TABLE I.
RECOVERY OF BERYLLIUM ADDED TO 100 ML. SAMPLES OF NORMAL URINE WHEN ANALYZED BY NEWER METHOD (IN DUPLICATE)

Micrograms Be Added	Micrograms Be Found
Nil	Nil or <0.0025; Nil or <0.0025
0.0025	0.003; 0.002
0.005	0.006; 0.007
0.01	0.012; 0.014
0.05	0.055; 0.065
0.10	0.08; 0.09
0.20	0.25; 0.15

Table II shows the values obtained by the use of the improved method on 250 ml. and 500 ml. samples of urine, in comparison with those obtained by the earlier method which was limited to 50 ml. of sample.[2] It can be seen that the uncertainty of detection in the range of concentrations below 0.05 microgram of beryllium per liter is now removed by the new technique. In every case the quantities isolated by the acetylacetone procedure are either lower than or very close to, the limit of detection of the earlier method. Therefore, the values reported by us, as obtained by the use of the earlier method, were not greatly in error, and the agreement in the results in the higher ranges of concentration is satisfactory.

The present method of isolating beryllium from large volumes of solution of complex composition provides final solutions that show very little variation in salt composition. The material placed in the arc, therefore, except for its beryllium content, corresponds closely in composition to that of the spectroscopic buffer which was used to derive the calibration curves. This eliminates conditions which interfered with the sensitivity of detection of trace metals in the cathode layer method of quantitative spectrography. The only metal which ac-

TABLE II.
A COMPARISON OF RESULTS OBTAINED ON SAMPLES OF URINE ANALYZED BY BOTH THE EARLIER AND NEWER METHODS

Earlier Method		Newer Method	
Volume ml.	Micrograms Be/Liter	Volume ml.	Micrograms Be/Liter
50	Nil or <0.05	500	0.054
50	Nil or <0.05	500	0.08
50	Nil or <0.05	250	0.023
50	Nil or <0.05	250	Nil or <0.01
50	Nil or <0.05	250	0.025
50	Nil or <0.05	250	0.064
50	Nil or <0.05	250	0.038
50	0.10	250	0.44
50	0.30	500	0.26
50	0.08	500	0.18
50	1.0	500	1.92
50	0.66	500	1.04
50	0.56	500	0.85
50	0.24	250	0.43
50	1.08	250	1.32

companies the beryllium, following the use of the mercury cathode and acetylacetone steps, is aluminum which does not interfere spectrographically.

An attempt was made to substitute chloroform for benzene, so as to eliminate the use of the latter in general laboratory procedures, and to replace the stirring process (which was time consuming), with shaking by hand.

However, upon the addition of 0.05 microgram of beryllium to 250 ml. of a normal urine prepared for analysis in the manner described in the new method, no beryllium was recovered following shaking by hand for one minute when chloroform was used.

References

1. CHOLAK, J. and HUBBARD, D. M.: Spectrographic Determination of Beryllium in Biological Material and in Air. *Anal. Chem.*, 20:73 (1948).
2. CHOLAK, J. and HUBBARD, D. M.: Spectrochemical Determination of Beryllium. Increased Sensitivity of Detection in the Cathode Layer. *Anal. Chem.*, 20:970 (1948).
3. COMBES, ALPH.: The Valency of Glucinium and the Formula of Glucine. *Compt. rend. Acad. sc.*, 119:1221 (1894).
4. KLEMPERER, F. W. and MARTIN, A. P.: Determination of Traces of Beryllium in Biological Material. *Anal. Chem.*, 22:828 (1950).
5. MANNKOPFF, R. and PETERS, C.: Quantitative Spectral Analysis with the Aid of the "Negative Glow Layer" in the Electric Arc. *Ztschr. Physik*, 70:444 (1931).
6. PARSONS, C. L.: A Revision of the Atomic Weight of Beryllium. *J. Am. Chem. Soc.*, 26:721 (1904).
7. TORIBARA, T. Y. and CHEN, P. S., JR.:: Separation of Beryllium from Biological Material. *Anal. Chem.*, 24: 539 (1952).

Pneumotachography in the Study of Respiratory Dysfunction

PAUL E. MORROW, Ph.D.

Summary of a paper presented before the Western Section, American Industrial Hygiene Association, December 1, 1951.

PNEUMOTACHOGRAPHY pertains to the measurement and analysis of respiratory airflow dynamics. In recent years, pneumotachography has been applied to the study of normal human respirations and to the problems of design in resuscitative devices, respirators, and respiratory protective devices. Several efforts have been made to cated that the pneumotachograph may prove to be one of the more valuable tools in functions. More recent developments in the field of pneumotachography have indicated that the pneumotachograph may prove to be one of the more valuable tools in the study of respiration in laboratory animals, and it has indicated that respiratory kinetic measurements in man constitute a valuable supplement to existing lung function tests. The modern pneumotachograph is generally an electronic assembly which possesses high sensitivity and operates with a minimum resistance to the respiration of the subject. Properly designed pneumotachographs provide accurate volumetric data and permit studies of ambulatory subjects or in situations where portable operation is necessary.

Design Velocity in Industrial Exhaust Systems

ARTHUR C. STERN, Chief, Engineering Unit
Division of Industrial Hygiene and Safety Standards
New York State Department of Labor

THERE ARE FIVE elements in the choice of branch and main velocity in the design of industrial exhaust systems, namely: economy, balance, noise, transport, and abrasion. In exhaust systems for gases, vapors, and hot or humid air, only the elements of economy, balance, and noise need be considered since there is no particulate matter requiring maintenance of a minimum transport velocity and also no abrasion by the transported particles.

Economy

THERE IS, for any given set of design conditions, a most economical design velocity. It is the velocity at which the sum of the cost to own the branches and mains, and the cost to move air through them is at a minimum.

The cost to own the ductwork is itself the sum of two factors, namely, a capital charge on the investment in ductwork, and a rental charge for such otherwise usable space as may be taken up by the ductwork. The capital charge is determined by the purchase price of the ductwork, the period of depreciation, the salvage value of the installation, and the interest rate charged against the capital invested. For practical reasons, the salvage of the ductwork is assumed to be zero. Depreciation and interest charges may be combined into I, the annual fixed charge on the investment in percent.

The Bureau of Internal Revenue suggests a depreciation period of 20 years for industrial exhaust system ductwork but the period will be shorter in some industries. The annual interest rate on capital invested will vary between 3% and 10% per annum. From these considerations, an average annual fixed charge of about 10% was selected for these computations.

Cost of Ductwork

FOR EACH air quantity we may investigate the cost of owning and operating various sized ducts. Cost of erected ductwork is usually expressed as dollars per pound of steel (Z). Z includes the cost of raw material, fabrication, erection, and fittings such as elbows. The weight per running foot of duct increases with duct diameter due to the normal increase of duct circumference with diameter and the required increase of metal gage with increasing diameter according to some schedule such as Table I. The schedule selected is for non-abrasive and non-corrosive application and therefore covers the bulk of the applications in which transport velocity is not a factor. The expression for the annual capital charge on the cost of investment in ductwork in dollars per year may thus be:

$$\text{Annual Capital Charge} = \frac{IZWL}{100} \pi \frac{d}{12} \quad (1)$$

Where L is the length of duct in feet; d is duct diameter in inches; Z is the cost of erected ductwork in dollars per pound; W is the weight of sheet steel in pounds per sq. ft., and I is the annual fixed charge in percent.

The value of Z varies with geographic location and economic conditions. A value of 50c per pound was used in these com-

TABLE I.
GAGE AND WEIGHT OF GALVANIZED SHEET STEEL DUCT

	Gage	lbs. sq. ft.
Up to 8" duct	24	1.2
8" to 18" duct	22	1.4
18" to 29" duct	20	1.7
30" and over	18	2.2

putations. It represents 1951 costs in New York City as reported to us by local sheet metal contractors.

Space Rental Charge

THE NEED for a space rental charge for ductwork arises from the fact that when large air quantities are moved at low velocities, the cubage occupied by the duct becomes significant and may reduce otherwise usable workroom space.

As a practical matter, it is recognized that when the air quantity involved is small, e.g., 100 cfm, even low velocity ducts can almost always be run in such a manner as not to encumber usable space. Although such ducts do take up space, they cannot reasonably be charged full space rental in the same manner as large obstructive ducts. In the computations of this paper, this dilemma was met by charging 100% of the space rental charge for ducts 100" in diameter (or equivalent rectangular ducts) and over; and charging a percentage of the space rental charge numerically equal to the duct diameter (in inches) for all smaller sized ducts, i.e., 20% of the space rental charge (R) for a 20" diameter duct. This is an entirely arbitrary procedure but appears justified by the facts. Space rental on an annual basis in dollars per year can therefore be expressed for values of d equal to or less than 100":

$$\text{Space Rental} = \frac{d}{100} \; R \, L \, \pi \frac{d^2}{576} \qquad (2)$$

Where R is space rental per cubic foot in dollars per cubic foot per year and the other factors (L and d) are as defined in equation (1). For purposes of this computation, an annual space rental charge of 15c per cu. ft. per year was used. This includes all incidental space charges such as insurance, fire protection, etc.

It will be noted in equations (1) and (2) that once values noted are assigned to I, Z, W, and R, the cost to own ductwork can be expressed in dollars per foot of length per year for each nominal diameter (d). Table II is a tabulation of these values based on the assumptions heretofore noted.

TABLE II.
COST TO OWN DUCTWORK
Annual Fixed Charge—10%; Cost of Duct at 50c lb.; Space Rental at 15c cu. ft./year; Duct Gages as per Table I.

Diameter of Duct Inches	Annual Capital Charge—Dollars/Yr./Foot of Length —Equation (1)	Space Rental Charge—Dollars/Yr./Foot of Length —Equation (2)	Cost to Own in Dollars/Yr./Foot of Length
3	.047	.000	.047
4	.063	.001	.064
5	.079	.001	.080
6	.094	.002	.096
7	.110	.003	.113
8	.147	.004	.151
9	.165	.006	.171
10	.183	.008	.191
11	.202	.011	.213
12	.220	.014	.234
13	.238	.018	.256
14	.257	.023	.280
15	.275	.028	.303
16	.293	.034	.327
17	.312	.040	.352
18	.402	.048	.450
19	.423	.056	.479
20	.445	.066	.511
21	.467	.076	.543
22	.490	.087	.577
23	.512	.100	.612
24	.534	.113	.647
25	.556	.128	.684
26	.579	.144	.723
27	.601	.161	.762
28	.623	.180	.803
29	.645	.200	.845
30	.864	.220	1.084
31	.893	.244	1.137
32	.922	.268	1.190
33	.950	.294	1.244
34	.979	.322	1.301
35	1.01	.352	1.362
36	1.04	.382	1.422

Cost to Move Air Through Duct

THE COST to move air through the ductwork is primarily the annual cost of electric power. A secondary factor is the increased cost of motor and fan as design velocity increases. This latter factor is, within limits, somewhat offset by a decreased fan cost due to decreased fan size, and the fact that fan size is more a function of quantity than design velocity. Because of this, the factor of fan and motor cost was not included in these computations.

If an exhaust system is assumed to oper-

ate Y hours per year and use electricity costing P dollars per kilowatt hour, annual power cost in dollars per year will be:

$$\text{Annual Power Cost} = \frac{0.746}{6356} \frac{\text{h Q Y P}}{\text{e}} \qquad (3)$$

where h is the head which must be supplied by the fan to produce the movement of air through the duct, in inches of water; Q is air quantity in cubic feet per minute; e is the efficiency of fan and motor as a decimal, and Y and P are as defined above. Y has been taken as 2080 hours per year, and e has been taken as 0.56 which is a composite of a fan efficiency of 66.6% and a motor and drive efficiency of 85%. This analysis is based on power (P) at $0.018 kilowatt hour, a value recommended to us as being close to average cost of power to factories in this area.

There are two elements entering the computation of the head (h): friction loss and the entrance and exit losses. The friction loss varies according to the formula:

$$\text{Friction Loss} = \frac{12\ f\ L\ h_v}{d} \qquad (4)$$

where f is the friction factor; h_v is the velocity head in inches of water, $\left(\frac{V}{4005}\right)^2$, L and d are as previously defined, and V is duct velocity in feet per minute. Forms of equation (4) which eliminate f as a variable are too complex to use in this type of analysis. Therefore, values of friction loss were obtained from the A.S.H.V.E. friction chart.

Entrance and Exit Losses on Total Head

THE ENTRANCE and exit losses are proportional to h_v and may be defined as:

$$\text{Entrance and Exit Loss} = k\ h_v \qquad (5)$$

where k is a factor dependent upon the design of the system as a whole. The complete expression for the sum of equations (4) and (5) is therefore

$$h = \left\{\frac{12\ fL}{d} + k\right\} h_v \qquad (6)$$

which is substituted for h in equation (3).

The annual cost (A) to own and operate exhaust ducts may therefore be expressed by the sum of (1), (2), and (3) as follows:

$$A = \left\{\frac{\pi\ IZ\ W\ d}{1200}\right\} L + \left\{\frac{\pi\ R\ d^3}{57{,}600}\right\} L + \left\{\frac{0.746\ Q\ Y\ P\ h_v}{6356e}\right\}\left\{\frac{12\ fL}{d} + k\right\} \qquad (7)$$

The design duct velocity at which the sum of these three terms is at a minimum is the most economical design velocity.

To analyze the range of possible values of k, it is necessary to consider the following typical conditions:

1. *Entrance and Exit Velocity Substantially the Same.* This is the commonest type of system design. At the inlet there is a hood entrance loss depending upon the type of hood (e.g., 0.04 h_v for a bell-mouthed hood and 0.93 h_v for a plain duct end). At the exit there is a loss of one velocity head (i.e., 1.0 h_v). The value of k will, therefore, vary from 1.04 to 1.93 or higher for poorly designed hoods. In general, the range of k will be between 1 and 2.

2. *Exit Velocity Substantially Lower than Entrance Velocity.* Entrance conditions are the same as in the previous condition. The decrease in velocity may occur either at the exit, in the branches, or in the main, or in more than one of these locations. The system may be credited with whatever static regain is achieved by long tapered increasers. In such systems, the value of k would be lower than where entrance and exit velocities are equal, decreasing to as low as 0.26 for maximum possible regain of 78% and a bell-mouthed hood.

Most Economical Velocity

IT APPEARED easier to solve equation (7) for the value of d for minimum annual cost by trial and error methods rather than by differentiation and equation to zero. Calculations in this paper were made for values of k of 0, 1, and 2; values of Q of 100, 250, 500, 750, 1000, 2500, 5000, 7500, and 10,000 cfm; and values of L of 0, 10, and 100 feet and ∞. As L approaches 0 the expression $h_v\left(\frac{12\ fL}{d} + k\right)$ approaches kh_v. Therefore, the column in Table II for L = 0 was calculated by elimi-

nating the factor $\left(\frac{12\ fL}{d}\right)$ from equation (7). The average of this column was plotted in Fig. 1 as though L = 1 ft.

When L = 1000 ft., and d is close to the size to yield the most economical velocity, sample calculations show that the value of $\left(\frac{12\ fL}{d}\right)$ is so large compared to 1 or 2 (the value of k) that k can be neglected.

The results of the trial and error computation of most economical velocity are shown in Table III. The lack of a smooth relationship between airflow-rate and most economical velocity for the several conditions listed is caused by two factors: (a) Only whole sizes in which duct is commercially manufactured were used in the computations and (b) the increase of duct gage with duct size. Both these factors cause discontinuity in what would otherwise be a continuous relationship. Table III shows that length of duct is the most important variable in the selection of most economical velocity and that the effect of air flow rate becomes pronounced only where the run of duct is long. The effect of length becomes most evident by plotting the average of velocity values against length as in Fig. 1. It will be seen also that the difference caused by VP decreases with increasing duct length.

For duct lengths between 10 and 100 feet, the most economical velocity computed, using the assumptions already noted, lies in the range of from 1000 to 1750 fpm for systems having entrance and exit velocity substantially the same. For systems having exit velocity substantially lower than entrance velocity and effective static regain of the difference, most economical velocity is several hundred fpm higher.

Balance

BALANCE in an exhaust system is the uniformity of air flow through branches at different distances from the fan. In poorly balanced systems, the branches farthest from the fan are starved for air while those nearest the fan get too much. In this study, the measure of balance is the ratio of air flow in the branch farthest from the fan to the air flow in an otherwise identical branch nearest the fan. As balance improves, this ratio approaches unity.

Balance ratio was computed as the square root of the ratio of (a) branch static pressure* to (b) the sum of branch static pressure and the frictional resistance of the main between the farthest and nearest branches. The effects on this ratio of branch and main velocity, length and air quantity were investigated by assuming a tapered main of uniform main velocity fed by equally spaced identical branches each at the same design branch velocity.

For the purpose of this study, branches were assumed to each have two 90° elbows,

*At design branch velocity and at the branch to main junction.

TABLE III.
EFFECT OF DUCT LENGTH, AIR FLOW RATE AND VELOCITY HEAD ON MOST ECONOMICAL AIR VELOCITY IN DUCTS

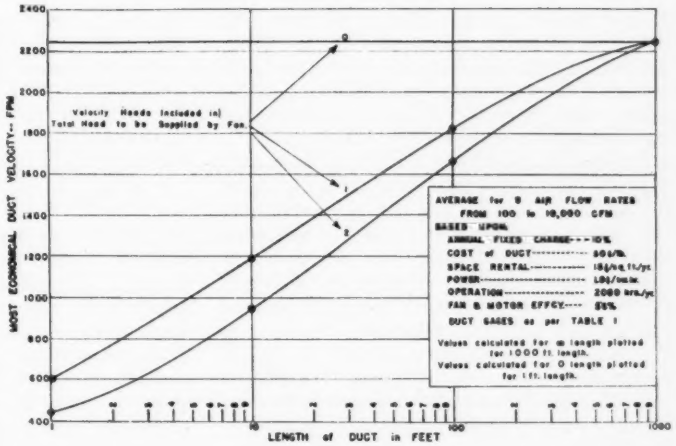
Air Flow Rate in CFM	Most Economical Air Velocity in FPM Length of Duct in Feet 0*	10	100	∞**
	One Velocity Head to be Supplied by Fan		Included in Total	
100	730	1500	1500	2000
250	800	1080	1830	1700
500	530	1600	1600	1850
750	520	1140	1650	2400
1000	620	1080	1800	1800
2500	540	1150	2040	2000
5000	540	1090	1850	3200
7500	530	1060	2000	2550
10000	580	1080	2150	2700
Average	599	1198	1824	2244
	Two Velocity Heads to be Supplied by Fan		Included in Total	
100	430	904	1500	2000
250	500	930	1830	1700
500	430	920	1600	1850
750	400	960	1500	2400
1000	380	815	1500	1800
2500	540	800	1750	2000
5000	380	1090	1550	3200
7500	470	1060	1600	2550
10000	425	990	2150	2700
Average	439	941	1664	2244

NOTE: Annual Fixed Charge—10%; Cost of Duct at 50c lb.; Space Rental at 15c/cu. ft./yr.; Power at 1.8c/kw. hr.; Operation for 2080 hours/year; Fan and Motor Efficiency—56%; Friction loss from ASHVE Friction Chart.

*This column is assumed to represent duct length of one foot for purposes of graphical presentation.

**This column is assumed to represent duct length of 1000 feet for purposes of graphical presentation since there is no substantial difference between the value for 1000 feet and ∞. This column actually represents the omission of Velocity Head from the Total Head to be supplied by the fan and is therefore identical in both parts of the above table.

terminate in identical hoods having a ¾ VP entrance loss, and enter the tapered main at ten foot intervals. Branch static pressure was thus 2½ branch VP's plus the frictional resistance of the straight pipe in the branch. (The 2½ VP consisting of ¾ VP hood entrance loss, ½ VP elbow loss, ¼ VP branch to main transition loss and 1 VP velocity head.) The A.S.H.V.E. friction chart was used to compute both the resistance of straight pipe in the branch and tapered pipe in the main.


MOST ECONOMICAL DUCT VELOCITY — FPM
LENGTH of DUCT in FEET
Velocity Heads Included in Total Head to be Supplied by Fan
AVERAGE for 8 AIR FLOW RATES FROM 100 to 10,000 CFM
BASED UPON:
ANNUAL FIXED CHARGE — 10%
COST of DUCT — $04/lb.
SPACE RENTAL — 15¢/sq. ft./yr.
POWER — 1.0¢/m.h.r.
OPERATION — 2000 hrs./yr.
FAN & MOTOR EFFCY — 55%
DUCT GAGES as per TABLE I
Values calculated for straight plotted for 1000 ft. length.
Values calculated for O length plotted for 100 ft. length.
Fig. 1.

Effect of Variables on Balance Ratio

THE PRINCIPAL variable investigated was branch and main velocity. All combinations of velocity in steps of 1000 fpm between 2000 and 6000 fpm were studied for 200, 500, and 800 cfm per branch for the particular condition of branch length equal to 15 feet and main length equal to 50 feet (Table IV). Other studies were made at 500 cfm per branch by varying

TABLE IV.
EFFECT OF BRANCH VELOCITY, MAIN VELOCITY AND AIR QUANTITY ON BALANCE RATIO

Branch Velocity in FPM	Balance Ratio — Main Velocity in FPM					
	1000	2000	3000	4000	5000	6000
	200 CFM per branch					
1000	.84	.56	.37	.26	.21	.17
2000	.96	.81	.62	.49	.40	.32
3000	.99	.91	.79	.67	.57	.48
4000	.99	.95	.87	.78	.69	.60
5000	.99	.97	.91	.84	.77	.69
6000	.99	.98	.94	.88	.83	.76
	500 CFM per branch					
1000	.89	.64	.46	.33	.26	.20
2000	.97	.86	.72	.57	.47	.39
3000	.99	.93	.84	.73	.63	.54
4000	.99	.96	.90	.82	.74	.66
5000	.99	.98	.93	.88	.81	.74
6000	.99	.99	.96	.92	.87	.81
	800 CFM per branch					
1000	.91	.69	.48	.36	.29	.23
2000	.98	.88	.74	.61	.52	.43
3000	.99	.95	.86	.77	.68	.59
4000	.99	.97	.91	.85	.78	.70
5000	.99	.99	.95	.90	.85	.78
6000	.99	.99	.97	.93	.89	.83

NOTE: Six identical 15 ft. long branches entering 50 ft. long tapered main at 10 ft. intervals. Each branch with two 90° elbows and hood having 0.75 V.P. entrance loss.

TABLE V.
EFFECT OF LENGTH OF BRANCH ON BALANCE RATIO

Branch Velocity in FPM	Main Velocity in FPM	Balance Ratio — Length of Branch in Feet				
		7½	15	30	60	120
4000	4000	.81	.82	.85	.88	.92
5000	3000	.92	.93	.95	.96	.97

NOTE: Six identical branches entering 50 ft. long tapered main at 10 ft. intervals. Each branch with two 90° elbows and hood having 0.75 V.P. entrance loss—500 cfm per branch.

TABLE VI.
EFFECT OF LENGTH OF MAIN ON BALANCE RATIO

Branch Velocity in FPM	Main Velocity in FPM	Balance Ratio — Length of Main in Feet							
		20	50	80	110	140	170	200	230
4000	4000	.89	.82	.78	.77	.75	.73	.70	.69
5000	3000	.96	.93	.92	.91	.90	.89	.88	.87

NOTE: Identical branches 15 ft. long entering tapered main at 10 ft. intervals. Each branch with two 90° elbows and hood having 0.75 V.P. entrance loss—500 cfm per branch.

branch length from 7.5 feet to 120 feet (Table V), and varying main length from 20 feet to 230 feet, (Table VI) with both branch and main velocity at 4000 fpm and again with branch velocity at 5000 fpm and main velocity at 3000 fpm.

It seems reasonable to seek a design balance ratio of 0.9 or better. When both branch and main are at the same velocity, the only points where this is achieved among all the combinations studied are when, at 800 cfm per branch, the velocity is 1000 fpm or less, and at 500 fpm per branch and 4000 fpm velocity when branch length is 2.4 times main length; a highly unrealistic situation. In real situations, therefore, it is necessary to have branch velocity exceed main velocity in order for the balance ratio to reach 0.9. To achieve this, the main velocity must not, in most practical cases, exceed 4000 fpm; the ratio of branch to main velocity must exceed 1.25 for high (800) cfm per branch (1.4 for low (200) cfm per branch); and the length of branch must be at least 1/10 the length of main or have added branch resistance equivalent thereto.

Noise

AIR NOISE in exhaust systems originates more in the fan and the duct inlets and outlets than in the duct itself. Where fan noise is low and the inlets and discharge quiet, fairly high duct velocities may be used without the generation of objectionable noise. Unfortunately, high duct velocities are generally associated with high static pressures and high inlet and discharge velocities.

Because fan noise usually increases with static pressure and inlet-discharge noise increases with inlet or discharge velocity, systems employing high duct velocity are usually noisier than those with low duct velocity.

Since an industrial exhaust system must, by definition, be installed in a factory, background noise levels lower than 60 db may hardly ever be expected. When the background level is 60 db, air noise of the same level (60 db) would raise the room noise level to only 63 db. The air flow from or into an opening required to produce 60 db air noise is approximately as follows:*

Air Quantity CFM	Maximum Velocity At Opening FPM
100	10,000
500	6,500
1,000	4,500
5,000	3,000
10,000	2,500

Where the factory background noise level is higher than 60 db, as is usually the case, air velocities at openings higher than shown above may be readily tolerated as far as resulting noise is concerned. Therefore, if fan noise be considered a separate problem, it can be concluded that noise creation is no deterrent to the use of branch inlet velocities up to 6000-10,000 fpm range, and main discharge velocities up to the 3000-5000 fpm range.

Transport

IN A PREVIOUS paper** test results of minimum required transport velocity for a number of substances were published. They ranged from a minimum of 1500 fpm for leather sander dust to a maximum of 4000 fpm for aluminum chips and various hogged materials (wood wood composition and rosin).

That paper contained the following statement: "It is to be noted that our recommendations are for minimum safe transport velocities, not design velocities. Actual design velocities should not be less than these minimum transport velocities, but may be greater, according to the judgment of the design engineer. The actual design velocities must take into account such factors as the use of blast gates, chip traps, probably poor maintenance, and the possibility of picking up material other than that for which the exhaust system is designed."

Additional studies, as yet unpublished, made on the same test setup used to obtain the above results, have shown that even when an exhaust system handles only previously air-floated dusts having terminal velocities under 300 fpm, sufficient ag-

*Adapted from Fig. 9, Chapter 10, 1951 ASHVE Guide, p. 881.

**BALIFF, J., GREENBURG, L., STERN, A.C.: Transport Velocities for Industrial Dusts—An Experimental Study. *New York State Department of Labor Monthly Review*, 28:12, 1949.

glomeration occurs in the main to require transport velocities several times terminal velocity to keep the bottom of the main free from settled dust. It therefore appears that there is a minimum transport velocity of about 1000 fpm required whenever particulate matter is to be moved and that it is generally unwise to use a design velocity for dusty air of less than 2000 fpm. For cast iron machining, it is not uncommon to use branch design velocities between 5500 and 6000 fpm to prevent settlement of the cast iron chips in the duct. Transport velocity can be kept as low as 2000 fpm if chip traps or primary rough separators are used near each hood to prevent large particles or extraneous matter from entering the branches. Otherwise, transport velocity must be high enough to move through the system the largest particle of object likely to enter it. To select design velocity for effective transport, each proposed system must be studied on its own merits. The great majority of dust carrying exhaust systems are designed in the 3000-4000 fpm range and operate in the 2500-3500 fpm range.

Abrasion

THERE IS practically no information available on the relation of duct velocity and duct abrasion. We know in a general way that increasing velocity increases abrasion and therefore recommend design velocities as low as possible when abrasive materials are exhausted. Unfortunately, an abrasive material usually requires a relatively high transport velocity. Thus, a chip trap or primary rough separator may be the answer to the conflicting demands of low branch velocity to reduce abrasion and high transport velocity required to move heavy particles.

Conclusions

WHERE NO DUST is handled, the primary basis for selecting design velocity should be the most economical velocity for the length of branch and main involved. The resulting branch and main velocity should be checked for balance ratio. If balance ratio is not within acceptable limits, branch velocity should be increased and main velocity decreased from the most economical values enough to achieve an acceptable balance ratio. At the velocities involved, noise need not be considered.

Where dust is handled, transport velocity will invariably be the basis for selecting design velocity, since in almost all cases transport velocity will exceed most economical velocity. The resulting branch and main velocity should be checked for balance ratio. Since transport velocity must be maintained in the main an unacceptable balance ratio can be corrected only by increasing branch velocity. This increase should be as low as possible to minimize branch abrasion. It is usually unnecessary to consider noise as a factor.

Summary

1. A METHOD for computing most economical velocity is outlined. Under certain assumed and stated cost and operating conditions, it is shown that most economical duct velocity lies in the range of from 1000 to 1750 fpm for exhaust systems having entrance and exit velocity substantially the same. This range is several hundred fpm higher in systems having exit velocity substantially lower than entrance velocity and effective static regain of the difference between entrance and exit velocity head.

2. A method for computing system balance ratio is outlined. Under certain assumed and stated operating conditions, it is shown that to achieve an air flow in the branch farthest from the fan 90% or more of that in the identical branch nearest the fan in a system having a multiplicity of branches, main velocity must not, in most practical cases, exceed 4000 fpm; the ratio of branch to main velocity must exceed 1.25 for high (800) cfm per branch (1.4 for low (200) cfm per branch); and the length of branch must be at least 1/10 the length of the main or have added branch resistance equivalent thereto.

3. It is shown that noise creation is no deterrent to the use of branch inlet velocities up to the 6000-10,000 fpm range and main discharge velocities up to the 3000-5000 fpm range.

4. Requirements for maintaining dust transport velocity and the abrasive action of high transport velocity are discussed.

5. A general procedure for selecting design velocity is outlined for exhaust systems which handle dust and those which do not.

The Measurement of Industrial NOISE

I. Introduction

INDUSTRIAL NOISE conditions have in recent years become of increased importance because of the possibility of loss of hearing. It therefore becomes necessary to survey methods of measuring noise and the related equipment so that required measurement information and techniques can be simplified and standardized if possible for the benefit of personnel who are concerned primarily with permissible noise levels and the control of noise conditions. The present work is a manual specifically for these purposes.

The attempt has been made to include only material that is of interest to the safety man, the industrial hygienist, and the engineer, all of whom are directly concerned with the problem. Acoustical principles and equipment information which are necessary to an understanding of the noise measurement problem are described. The presentation is such that the worker can use the material with but little previous experience in acoustics.

II. Principles of Sound

A. GENERAL: Before sound can be measured, it is necessary to understand what is being measured. According to current standards,[1] sound is an alteration in pressure, stress, particle displacement, particle velocity, etc., which is propagated in an elastic material, or (A) the superposition of such propagated alterations. A second definition from the same standard states that sound is the auditory sensation which is usually evoked by the alterations described above. Sound is, then, the physical condition in the medium and also the subjective sensation produced in the human brain.

In simpler, less technical terms, sound or noise is the result of variations in air pressure above and below atmospheric caused by a vibrating source, as well as the sensation produced. A sound or noise condition is, therefore, a wave motion in the air set up by a vibrating body or by a series of pulses of air, steam, or gas. This wave motion, also known as a sound wave, consists of compressions and rarefactions in the air due to the motion of the source or its parts. Since air is an elastic medium, it transmits this motion. Furthermore, the air movements are extremely small. For instance, the distance that a particle oscillates from its rest position for a 1000 cps tone at a level of 94 db is 0.00005 inch. The speed of the audible sound waves in air is about 1120 feet per second.

The frequency of such sound waves is the number of times in a second that the cycle of compressions and rarefactions occurs. If the noise causes 500 air compressions and rarefactions in a second, then the frequency is said to be 500 cycles per second.

B. SOUND AND NOISE SOURCES

1. Production of Sound: One of the

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This article is a manual on the measurement of industrial noise. It is written for use by technical personnel in industry. Sufficient engineering content is supplied to enable good measurements to be made. For further detailed information, references to the most recent literature are given. The material is divided into several parts. After the introductory section, the principles of sound that apply to measurement are described. This section is devoted to the ear, the production and nature of sound sources and certain properties, the decibel notation, and characteristics of noise. The third part describes the various instruments, techniques, limitations and precautions which are necessary for satisfactory and meaningful measurements. A description is given for sound level meters, the various analyzers, microphone and measurement techniques, and such auxiliary equipment as magnetic recorders and paper chart level recorders. The fourth part is devoted to the calculation of loudness, and the fifth describes a typical measurement procedure carried out in detail.

(B-1) simplest types of device which can set up compressions and rarefactions in the air is a tuning fork whose prongs can be seen to move and thus create the wave motion. The diaphragm of a loudspeaker reproducing

(B-1) the simple pure tone of a flute is a similar example. When a complex wave shape consisting of a fundamental note and one or more harmonics or overtones is impressed on the voice coil of a loudspeaker, the diaphragm moves under dynamic conditions which reproduce the same complex wave motion in the air. The instruments of the orchestra individually cause thousands of wave motions in the air which travel outwardly to the listener. Most music such as this is pleasant to listen to, and in most cases all frequencies which are produced bear a relation to the lower notes which can be expressed as whole numbers such as 1, 2, 3, 10, 20, etc.

Noise, on the other hand, usually consists of wave motions in the air (or sensations in the ear) which are unrelated in frequency and in time. Noises such as the clatter of a punch press, the hiss of an air ejector, and the impact of one member on another consist of random frequencies which also are of a transient character.

A machine emitting noise has many surfaces or radiating areas which produce unpleasant sound such as the last example above. The radiating surfaces may be sheet or cast metal housings, gears, hammer-like members striking against anvil-like members or many other such small or large areas. The radiating surfaces are more significant the larger they are. In order to make an in-

(B-1) tense noise, either a large area may be vibrated with small amplitude or a small area may be vibrated with extremely high amplitude. The radiating source in each case usually is a member which is driving the radiating surface.

A simple illustration of the radiating surface separated from the source is that of the violin. The vibrating string is the source after it has been bowed or plucked. The vibrational energy is transmitted through the bridge to the body, and the body does the radiating. If the body were removed or greatly reduced in area, the instrument would not sound nearly so loud, since there would be no large surfaces to couple the vibrations to the air. In some cases, noise can be produced without a solid radiating surface. For example, fluctuating pressures in escaping air or steam or the spent-air exhaust of a pneumatic machine may produce intense sound.

A good example of a common noise source with complicated sources and radiators is the industrial blower. It may supply air for ventilating an area or for cooling purposes. The audible noise might be the whine of the fan blades or the air rush noise in the duct or at the grille. The noise often may be associated with other parts of the ventilation system. The actual source is a revolving electric motor shaft directly coupled to the blower fan. When new, the rotating shaft and fan are well balanced, but generate noise due to turbulences at the blades. This noise is transmitted by air to adjacent ducts made of sheet metal and which are ideal sound radiators. Furthermore, these noises are transmitted along the duct to the distant parts which also radiate. As the motor and fan bearings become worn, the shaft becomes unbalanced with resultant vibration of the motor and motor and fan housings. The magnetic circuit also is likely to cause vibration. This vibration is then transmitted to the block, wall, or

(B-1) other support to which the equipment is bolted. These supporting structures then vibrate at various frequencies and radiate noise.

2. Classification of Noise: For present purposes, industrial noises may be broadly classified as (a) steady state noises in which discrete tones stand out, (b) steady state noises in which no discrete tones predominate, and (c) transient noises. Transient noises are those which are not steady. They may vary in pitch or frequency or in loudness, or they may be intermittent. Automobile horns, sirens, some high speed compressors, and many pitched vibration devices can be placed in the first group. Internal combustion engines, ball mills, heavy complex mechanical equipment, pneumatic concrete-breaking drills, etc., are typical of machines that provide relatively unpitched steady state noises. Most of the noise in these can be identified as having few or no pitched tones. Typical machines which produce a transient type noise are drop-forging hammers, slow punch presses, metal cutting shears, and other machines that make short-lived noises with short rise times. When such transient noises are repeated at a rate of about one cycle per second or slower, they become quite difficult to measure accurately. These different groups will be of importance later in analyzing noise.

C. PHYSICAL PRINCIPLES

1. Sound Pressure: As described previously, sound and noise are physical conditions in the air. Many of these physical characteristics can be measured. For measuring sound pressure, it is convenient to establish a reference condition. The effective sound pressure in the air for this reference condition is 0.0002 dynes per square centimeter, or 0.0002 microbar. This pressure is approximately that which exists in the air for the sound of a 1000 cps pure tone which can just be heard by a person with acute hearing. Various other definitions in acoustical terminology can be found in the literature.[1,2,3,4,5]

TABLE I.
TYPICAL SOUND PRESSURE LEVELS AND SOUND PRESSURES

Condition	Sound Pressure Level, db	Sound Pressure, Microbars
Pain Threshold	130-140	600-2000
Feeling Threshold	120	200
Airplane, DC-6 (inside)	104	32
Very Noisy Factory	100	20
Subway Car	94	10
Automobile	92	8
New PCC Streetcar	90	6
Street Corner Traffic, Large City	75	1.1
Loud Radio	74	1
Typical Office	60	0.2
Average Living Room	40	0.02
Very Quiet Home	20	0.002
Audibility Threshold	0	0.0002

(C) 2. The Decibel Notation: Alternating sound pressures of 0.0002 to 2000 microbars exist in air for the usual range of audible sounds. Because of the difficulty which would be experienced in using numbers in this range to describe physical conditions for sounds, the decibel notation has come into general use.

The decibel is one tenth of a bel, a logarithmic unit which was named after Alexander Graham Bell. The number of bels corresponding to a sound pressure, P_1, is equal to the logarithm of the square of the ratio of this presure to the reference pressure P_0 already mentioned. The number of decibels, abbreviated db, then will be ten times the number of bels. This is referred to as the sound pressure level. Thus:

$$db = 10 \log (P_1/P_0)^2$$
$$= 20 \log P_1/P_0$$

Using the decibel to describe sound pressure conditions, sound pressures of 0.0002 and 2000 microbars represent sound pressure levels of 0 and 140 db respectively.

Table I shows a comparison of sound pressure levels in db and sound pressures in microbars. Examination of this table will permit a better correlation with the sound pressure levels and the corresponding physical conditions in the air.

D. THE EAR AND HEARING

1. The Ear: It is not within the scope of this work to describe the physiology of hearing.[6] It is pertinent, (D-1) however, to indicate some of the characteristics of the ear. The range of audible frequencies is from approximately 15 cps to 15,000 cps for the average person with normal hearing. Some people, especially children, can hear even higher frequencies. Reference to Table I will show that the range of sound pressure which can be heard is tremendous, extending from below 0.0002 microbar to above 2000 microbars. In addition, the ear constitutes a sensitive sound analyzer, in that as sounds are heard, the brain sorts them accordingly as they are high, medium, or low with all intermediate gradations in frequency. The two ears also constitute a sensitive system for efficiently locating a sound source.

It can be seen that the ear measures subjectively many of the physical properties of sound. It is important to point out that the ear measures loudness of sounds also, and one of the difficult goals of acoustical scientists is to devise a meter that will agree with the ear in these measurements. This is difficult because the ear does not have the same response to all frequencies. That is, the loudness of sound as interpreted by the ear does not have a direct relationship to the intensity measured in decibels at the various frequencies.

2. Equal Loudness Contours: The variation in response of the average normal ear to pure tones is shown graphically in Fig. 1. Each curve represents a single loudness level as judged by the ear. Vertical height on the curve indicates the sound pressure levels in decibels required to produce an equal sensation of loudness for each of the various frequencies indexed at the bottom of the graph. These curves are called the "Fletcher-Munson Equal Loudness Contours" after the men at Bell Telephone Laboratories who pioneered in the work. The unit of loudness level is the phon. The loudness level in phons of a pure tone is numerically the same as the sound

(D-2) pressure level in decibels of a 1000 cycler per second pure tone that sounds equally loud. It will be noted that the loudness level curves on Fig. 1 all coincide with the corresponding decibel levels at 1000 cps and with this point as a reference the rest of each curve has been developed.

The curves in this figure corresponding to low loudnesses were based on people with excellent hearing. For average adults, some of whom will have somewhat better hearing and some of whom will have worse because of different degrees of hearing loss due to damage or aging, the average threshold will be around 15 phons. The spread of these individual thresholds will be over a range greater than 15 phons.

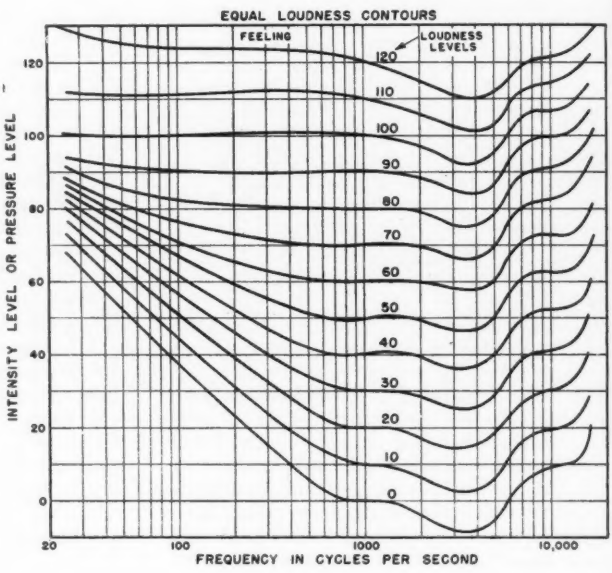


Fig. 1.
The Fletcher-Munson equal loudness contours.

For many reasons an arithmetic rather than a logarithmic unit of loudness of noise is desirable. This simpler unit of loudness is the sone. It is an arithmetic unit, such that a sound of 200 sones sounds twice as loud as one of 100 sones. With this unit, the loudness as interpreted by the ear is directly related to the number of sones. For the present purpose, one sone is the loudness of a 1000 cps tone 40 db above 0.0002 microbar. In the remainder of this article, sones will be used to describe loudness rather than phons to describe the loudness level.

3. Loudness of Complex Sounds: Much work has been done toward establishing the validity of the above statements regarding loudness when applied to pure tones. Furthermore, the sound level meter has been used with fair success in weighting single (D-3) pure tones so that resulting readings satisfactorily describe the loudness level. But when measuring complex sounds such as machinery noises or combinations of closely spaced pure tones, the sound level meter fails to indicate loudness, since the ear judges such sounds in a more complicated way than it judges pure tones.

Regardless of these difficulties, recent measurement techniques have enabled a simple loudness calculation to be made for complex noises. This is described later. The importance of an acceptable technique for loudness measurement is mentioned later.

III. Measuring Equipment and Techniques

A. Sound Level Meters

1. Description: The basic instrument for the measurement of noise is the sound level meter, but it should nearly always be used in conjunction with analyzing equipment. Essentially, the sound level meter consists of a microphone, and amplifier, and an indicating meter. The microphone

(A-1) responds to the alternating pressure due to the sound waves, and the resulting microphone voltage is amplified. The meter indicates this voltage in decibels referred to the reference sound pressure level. The American Standards Association has a standard[7] for performance of this equipment and sound level meters now available meet these specifications. Even with adherence to these standards, instruments of different manufacture or even of the same manufacturer do not read exactly alike, since the tolerances in the design objective are rather broad. The manufacture of this type of electronic equipment requires a tolerance which permits a variation from the design objective, and the standard[7] defines this tolerance as about plus or minus 3 db. The apparent error in a meter is then reduced with proper calibration as mentioned later. Sound level meter standards also specify the frequency range to which the meter should respond. This is from about 30 to 8000 cycles per second.

Although the response of the sound level meter can be made somewhat like that of the ear by the use of one of three electronic filters known as networks, its indications do not correlate well with the ear's estimation of loudness. Since the sound meter should generally be used with equipment for analysis, the A and B networks provided generally are not of much value. The C or FLAT network is recommended when making analyses. When using this network, all frequencies measured are weighted approximately equally.

One of the less satisfactory elements of the sound level meter is the microphone. Currently-used microphones represent a compromise in stability, ruggedness, sensitivity, frequency response, and cost. Both the Rochelle Salt crystal and the dynamic type microphones have been used widely in sound meters. The first-mentioned is the so-called crystal unit, and the second consists of a coil of wire mounted on a diaphragm

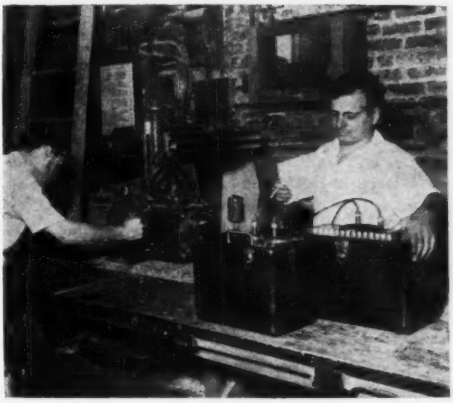


Fig. 2.
Sound measuring equipment for measuring industrial noise.

(A-1) and movable in a magnetic field. These are suitable for ordinary work, but their limitations should not be overlooked. For instance, the Rochelle Salt microphone must not be operated in temperatures around 100° F without suitable correction, for accurate measurements. Higher temperatures are encountered when a sound level meter is left in an automobile parked in the sun on a hot day, and this may result in permanent damage to this type microphone. The temperatures to which a crystal microphone is exposed should not exceed about 115° F. A temperature of about 125° F. will damage the crystal. The crystal microphone should not be exposed for lengthy periods to a relative humidity outside the range of about 30% to 80%. For precise laboratory work, a special dynamic or condenser microphone can be substituted for the one supplied with the sound level meter.

A complete description of various types of microphones and their applications is beyond the scope of this report. For further information reference should be made to a standard text or to published papers.[2,8]

The range of sound levels for which the sound meter can be used is from about 25 db to 130 db for

(A-1) some instruments and to 140 db for others. Measurements at the extreme ends of this range must be viewed with caution because of such reasons as circuit noise at the low sound levels and difficulties due to microphonics or instrument component vibration at high levels.

In order to be used with analyzing equipment, sound level meters must have circuit designs such that the voltage obtained at the output jack has a high degree of fidelity with respect to the input energy. The analyzer instructions in this regard should be followed. Fig. 2 shows one sound level meter at the left and its associated octave analyzer at the right (specified in Table II as numbers 2a and 6) in an arrangement to measure a typical industrial noise. Fig. 3 shows another arrangement with equipment of different manufacture (Table II, numbers 1b and 7) with the sound level meter at the left and the octave analyzer at the right.

It is often convenient to use an extension cable between microphone and meter. Manufacturers provide standard cables and indicate the correction when one must be used. In general, the correction for use of a short cable (6-10 ft.) with a dynamic microphone is negligible, while that for a crystal microphone is greater.

Most sound level meters have self-contained batteries, hence are portable. Power supplies are available for some, making them usable from the 110 volt line. These are pointed out in Table II. The table also gives the weights of the various instruments.

2. Sound Level Meters of Various Manufacturers: It is desirable at this point to present a list of sound measuring equipment and manufacturers. The attempt has been made in Table II to list available equipment, including instruments used in the past, which are best suited to the needs of measurement in the field. In some cases the different models by the same manufacturer are not identical

(A-2) in performance and differences may be of importance.

3. Calibration: Sound measuring equipment requires periodic calibration to be sure that it is in working order and that its indications are correct. The term "calibration" used here covers three procedures (a) a simple operation covering the electrical circuit of the sound level meter but not its microphone, (in Table II, instruments 1a, 1b, 2a, 2b, 2c, 2d, 4,

TABLE II.
LIST OF SOUND MEASURING EQUIPMENT

No.	Model	Weight Lbs.	Manufacturer
	Sound Level Meters		
1a	1551A	11	General Radio Co.
1b	Types 759A, 759B	22	General Radio Co.
	These two instruments are now superseded by the 1551A meter.		
2a	RA 358 (battery operated)	25	Western Electric Co.
2b	RA 359 (110 volt, 60 cycle)	25	Western Electric Co.
	Equipments 2a, 2b, and 6 are no longer available, but their exact equivalents 2c, 2d, and 6a are now available.		
2c	700A (battery operated)	25	Techno Instrument Co.
2d	701A (110 volt, 60 cycle)	25	Techno Instrument Co.
3	Cat. No. 5122145 G 1	19	General Electric Co.
4	410B	2.5	H. H. Scott, Inc.
5	54A	39	Allison Laboratories
	This instrument has a self-contained filter which provides octave bands. This company is developing a new instrument for the same purpose but weighing about half as much.		
	Octave Band Analyzers		
6	RA 360	55	Western Electric Co.
	For use with either RA 358 or RA 359 meters above. This instrument is no longer available. (See 2a and 2b above), but its exact equivalent 6a is now available.		
6a	731A Octave Filter Set	55	Techno Instrument Co
7	1550A	27	General Radio Co.
	For use with 759B or 1551A meters. May be used less satisfactorily with 759A meter.		
8	Number 5 above includes a filter in the same case suitable for use as an octave analyzer.		
9	420A	12	H. H. Scott, Inc.
	Narrow Band Analyzer		
10	760B	37	General Radio Co.

Addresses of Manufacturers

General Radio Co., 275 Massachusetts Avenue, Cambridge 39, Massachusetts
Techno Instrument Co., 6666 Lexington Avenue, Los Angeles 38, California
General Electric Co., Apparatus Department, Schenectady, New York
H. H. Scott, Inc., 385 Putnam Avenue, Cambridge 39, Massachusetts
Allison Laboratories, 419 Vista Del Llano, Whittier, California

(A-3) and 5), (b) a single tone acoustical calibration which includes the microphone in addition to the electrical circuit (in Table II, instrument 3, and instruments 1a and 1b when used with a specially provided calibrator), and (c) a complete overall calibration made by the manufacturer or a reputable laboratory such as the National Bureau of Standards. It is recommended that an overall calibration be made by the manufacturer when the equipment is purchased.

The instructions for all sound level meters suggest frequent calibrations such as in (a) or (b) above. This type of calibration should be made each time the equipment is used, and several times during extended tests. In some early models (Table II, number 1b), the manufacturer had provision for calibration (a) only. The microphone is not included in the calibration. In recent years, this company has supplied a calibrator which is placed on the microphone and emits a calibrating signal. Another sound level meter (Table II, number 3) is calibrated as in (b) by blowing a low-pitched whistle held near the microphone. When such audible signals are employed, the microphone is included in the calibration.

Any sound level meter that is in use should be returned to the manufacturer or to a reputable laboratory such as the National Bureau of Standards periodically for a complete overall calibration as in (c) above whenever it appears that its indications are not correct. The experienced user will recognize this condition when it occurs. It is recommended that the inexperienced user make noise level readings periodically on some steady noise source such as a business machine or fan commencing with the time he receives the equipment from the supplier. When measurements vary from the usual, then an investigation should be made, and if the sound measuring equipment is suspected, it should be re-

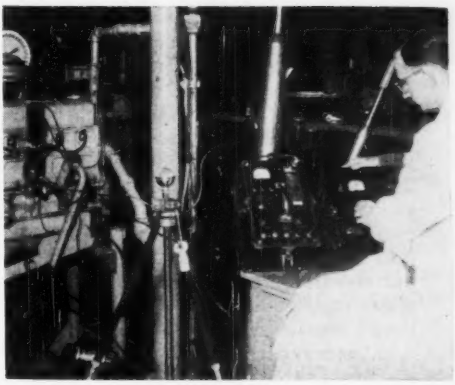


Fig. 3.
Sound measuring equipment for measuring industrial noise.

(A-3) turned to the manufacturer for inspection and calibration.

The overall calibration made by different manufacturers varies and the situation with regard to proper factory calibration of sound measuring equipment also is not completely satisfactory. The user, however, generally does not have facilities for such calibration, hence must rely on the manufacturer.

The above procedure will indicate to the user, first, whether or not the equipment is operating and, second, whether or not its indications are approximately correct.

If these calibration techniques are followed, the measuring equipment will be in good order at all times. Industrial noise generally is not steady from day to day mainly because of work operation changes. Extreme accuracy is not required since measurements made on one day may not agree with those at a later time. Properly calibrated equipment can be relied upon to provide absolute readings which are correct for the conditions when measured.

B. FREQUENCY ANALYSIS EQUIPMENT: Industrial noise consists of sound energy of many frequencies and it becomes desirable to be able to analyze these. Far more can be learned about a noise by analyzing it with respect to frequency

(B) and a picture of noise that indicates levels at various frequencies is much more satisfactory than a single overall level. Various types of noises were described earlier, and the analyzing equipment to be described here can be used with varying degrees of success to measure these. The type of equipment to use will depend on the type of information required. An analyzer is plugged into or otherwise connected to the output circuit of a sound meter. This explains the requirement for fidelity in sound measuring equipment.

In general, there are three types of equipment that can be used to analyze noise. These are (1) the octave band analyzer which is the most important type, (2) the constant-percentage narrow band type, and (3) the constant bandwidth, narrow-band analyzer which is probably of least importance in this discussion. For special purposes, use can be made of the recording speech analyzer which incorporates a special paper record of analysis, the panoramic analyzer which portrays the spectrum on a cathode ray tube, and various other types of analyzers, recording and otherwise, but since these instruments are not of interest in the present instance, the reader is referred to the literature.[2,8]

Present day instrumentation and techniques for the analysis of transient noises mentioned previously are unsatisfactory for use in the field. A complete discussion of such instruments is available in the literature.[2] Such equipment, however, generally is of the laboratory type. It is further described in a later section on the use of the oscilloscope. Since it is highly desirable to know the characteristics of transient noises made by slow punch presses, forging hammers, and other equipment, it is hoped that techniques can be improved in this respect in the future.

1. The Octave Band Analyzer: The purpose of the octave band analyzer is to measure industrial noise in octave bands. The instrument has proved more useful than other analyzers. It is especially applicable to measurement of industrial worker exposure

(B-1) to noise. This instrument is important for several reasons.

There has not been very much success in correlating industrial deafness with overall noise levels. There is much reason to believe that better correlation can be obtained with octave band levels and the problem is being worked on now by various agencies.

The octave band equipment is useful also in the computation of loudness of broad-band noises typical of those made by industrial equipment. Section IV shows why a numerical value for the loudness of noise is desirable. A method described by Beranek[2] indicates that certain bandwidths of broad-band noise are of equal importance in determining loudness. Bands one octave wide are close enough to the ideal that they may be used with reasonable engineering accuracy. Detailed information on the validity of such calculations would be lengthy and the reader is referred to very recent literature.[9,10]

The loudness in sones is advantageous because the resulting single number facilitates comparison of different kinds of noise. Such a figure is understandable and satisfactory to non-technical personnel. The loudness for most machines correlates better with ear judgments of the noise than does the overall sound level.

Another reason for the importance of octave band levels is that for most industrial noises they are more satisfactory in analysis techniques than other types of analysis. The octave analyzer is more satisfactory for measuring most industrial noises than the other two types of analyzers described later. This instrument can also be used to measure noises with or without discrete tones or combinations of these.

Equipment now in use provides for measurement in the following most-used bands: below 75 cps, 75-150 cps, 150-300 cps, etc., up to 2400-4800 cps and 4800 to 9600 or 10,000 cps.

(B-1) In certain instruments, other octave bands are provided. Octave band instruments therefore require measurements in only eight bands, and the time for analysis is reasonable for field work. Figs. 2 and 3 show typical octave band analyzers in use.

The limitations of this equipment must be realized. Most instruments are not sensitive with any degree of accuracy beyond the range of the microphone employed. Generally, such limitations are not serious. The user should keep in mind the characteristics of his equipment.

The procedure for making octave band measurements is simple in general, and as a rule is described adequately by the manufacturers. The various analyzers are listed in Table II. A number of precautions should be mentioned, however. One manufacturer (Table II, number 1b) discourages the use of the new octave analyzer with the older sound level meters because of unsatisfactory circuit characteristics such as circuit noise, distortion, and hum. Under certain conditions, hum may be picked up from a local magnetic field. In such cases high meter indications are given when the noise is not high. Often this interference can be heard as hum in the headphones when hum is not heard above the noise. Such pickup may be due to the filter or to the microphone if it is of the dynamic type. Another unusual condition sometimes is encountered when analyzing noise of small machines operated by electric motors with brushes and commutators. The sparking causes electrical noise in the meter circuits and results in higher meter indications than are due to airborne noise. This interference may be heard with a pair of headphones plugged into the output jack of the sound level meter. The remedy in many such cases is to connect a small condenser across the arcing contacts.

The indications of the octave band analyzer are complete for many purposes. However, the output of the

(B-1) analyzer can be heard with headphones for monitoring, displayed on a cathode ray oscilloscope for visual inspection, recorded on a graphic level recorder for permanence, or recorded by a magnetic recorder for later reproduction or analysis. This auxiliary equipment is mentioned later.

In Fig. 4 are shown octave band levels for two typical industrial noise sources. These particular sources are shown because each had the same overall sound pressure level. One source had predominantly low frequency energy, however, and the other had higher levels at high frequency. It can be seen that octave levels give much more information on the character of the noise than the overall levels give.

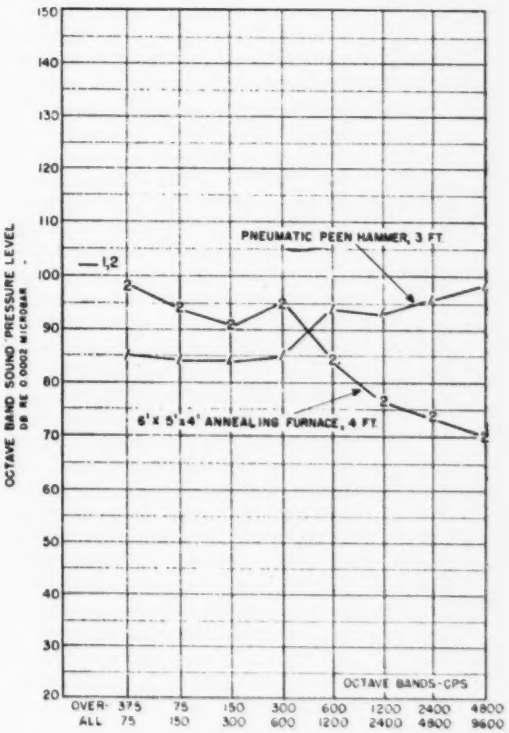


Fig. 4.
Octave band levels of two typical industrial noises.

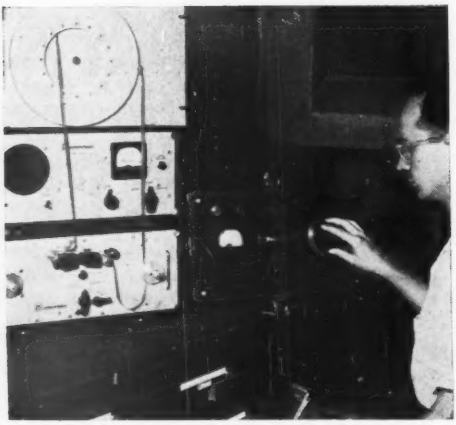


Fig. 5.
Magnetic recorder, tape loop mechanism, and analyzer for analyzing industrial noise.

(B) 2. The Narrow-Band Analyzer

(a) The Constant-Percentage, Narrow-Band Analyzer: The constant percentage, narrow-band analyzer is much less useful in industrial noise measurements than the octave band analyzer, especially for information relative to hearing damage. It can be used, however, when it is desired to determine sound levels at one or more single frequencies for noise control purposes. At least one manufacturer supplies this type of analyzer (Table II, item 10, and also described in the literature[11]). The bandwidth widens as the frequency increases and is about three percent of the frequency to which the instrument is tuned. The range covered by such analyzers corresponds to the important part of the audible range, approximately 25 to 7500 cps. This analyzer is shown in Figs. 5 and 6. It is battery-operated and suitable for use in the field when desired. In the first of these photographs the analyzer (Table II, number 10) is shown as used to analyze noise which has been recorded on tape with a magnetic recorder. The recorder consists of the two lower (B-2-a) units at the left. The unit above the recorder is a loop mechanism for feeding the tape continuously through the recorder while it is being analyzed.

Fig. 6 shows a sound level meter and analyzer (Table II, numbers 1b and 10) with a graphic level recorder for providing a written record of the analysis.

(b) The Constant Bandwidth, Narrow-Band Analyzer: Several manufacturers provide a constant-bandwidth analyzer of the heterodyne type. It is not useful for noise studies in general and requires a power line for operation. This instrument incorporates a circuit that passes and measures a very narrow band of energy. The bandwidth is fairly constant at all frequencies and although several widths of band usually are available, these are too sharp for general use.

Both narrow-band analyzers mentioned permit determination of discrete frequencies. The knowledge of frequencies and their relative levels is valuable in locating sources and radiating surfaces in machinery and controlling them. As mentioned before, however, the octave band analysis is generally more satisfactory than discrete frequency analysis.

C. USE OF THE EQUIPMENT IN THE FIELD: A description of the use of sound measuring equipment is not given here because the manufacturer's literature gives this information adequately and some differences exist in making the equipment operative. Under "A Typical Measurement Procedure" of this article is indicated in a general way how the equipment is operated in making measurements. A few remarks, however, are given here regarding operation and precautions.

The sound level meter and analyzer should be placed on a suitable table arranged so that the microphone will be in a proper position as described in a later section on microphone placement. It is desirable for the table to

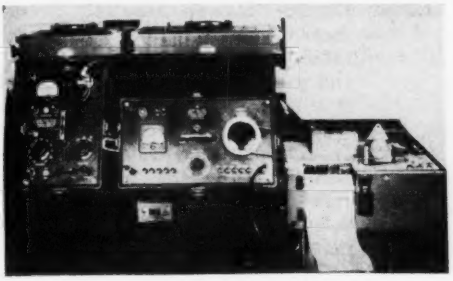


Fig. 6.
Sound level meter, analyzer, and graphic level recorder for noise analysis.

(C) be high enough to bring the instruments to a suitable height to facilitate adjustment and reading. If a number of measurements are to be made, use of a cart of suitable height in place of the table will facilitate moving the equipment from place to place.

Most current sound level meters and analyzers are provided with both fast and slow meter needle movements, either of which can be used by operating a switch. The design of the fast movement follows current specifications of the American Standards Association. The slow movement is such that the needle motion is damped to permit an average to be made of fluctuating indications. When a steady noise is measured, the same indications should be obtained with either movement.

Few industrial noises are extremely steady. Therefore, the indications using the fast movement often are such that the needle may have minimum and maximum readings which differ by one or more decibels. If the slow movement does not average these satisfactorily due to slow cyclical noise changes, then a mental averaging will be necessary. If the indicated range is from 90 to 96 db, for instance, the arithmetic average of 93 $\pm$ 3 db should be logged.

The floor of an area in which sound level readings are to be made may vibrate excessively so that the sound measuring equipment placed on a table or on a cart may give false readings. Such indications can be identified by lifting the measuring equipment with (C) the hands, resulting in lowered readings. This should be done in all octave bands if such difficulties are suspected. The trouble may be greatly reduced by placing the instruments on soft sponge rubber pads an inch or more thick.

Another difficulty that is sometimes encountered is the effect of microphonics, oscillation, or other troubles in the sound level meter or analyzer amplifier circuits. Microphonics are likely to occur in intense noise areas where airborne vibration (in contrast to structure-borne vibration mentioned in the preceding paragraph) causes the meter to give false indications. Such false readings may occur at levels of about 100 db measured in octave bands. In one commonly used analyzer, the presence of microphonics is indicated by a meter reading when the plug to the input jack of the analyzer is removed. If the instrument is operating properly each octave band level will be lower than the overall level. If the system is microphonic, this may not be true. Repositioning of the instruments may eliminate this difficulty at lower levels, but for levels higher than 120 db in octave bands it may be impossible to make readings. In such cases the distance to the source may have to be increased greatly to obtain indications. It may be possible to make readings by using a long microphone cable possibly running it through a window or door to another area. If the difficulty is due to microphonic tubes in the amplifier, these tubes should be replaced.

Incorrect meter readings can be avoided in such cases by using headphones in the sound level meter or analyzer output circuit at all times. If the sound heard in the headphones is not the same as that heard without headphones, then the equipment is not functioning properly. When such instrument difficulties are encountered, the equipment should be returned to the manufacturer.

D. SPECIAL MEASUREMENT TECHNIQUES: In general, sound measurement equipment is not difficult to use and the instructions provided are satisfactory. There are, however, a number of con-

(D) siderations which require special attention. Some of these are described below and further information on these and others may be obtained from a standard already mentioned[5] and a related one[12] on apparatus noise. Codes also have been prepared[13] for measurement of noise of specialized equipment of the same general type. These codes, however, are aimed at comparing overall noise levels of various machines rather than measurement of noise with respect to operator safety or comfort.

1. Microphone Techniques: The position of the microphone is important. Proper placement depends on the type of information desired. The sections below describe techniques for several different purposes.

(a) Microphone Placement for Noise Exposure Measurements: When noise measurements are being made to determine levels of noise to which an employee is exposed, the microphone should be placed in a region about which he moves. Most industrial noises are in enclosed spaces, the workman often is about four or five feet from the source, and he usually moves around so that his distance to the source is changing constantly. Under these conditions, the sound pressure level will be substantially the same for a relatively large area. Accurate distance measurements are therefore not necessary, but a distance of about three to five feet from the ear is suitable. If the workman is closer than several feet from the noise source for long periods of time, then the microphone should be somewhat closer to the ear, and more nearly the same distance to the source as the ear.

Under these conditions the noise measured may not be from the particular machine attended by the workman, but it is the noise condition to which he is exposed. The effect of background noise on levels measured near a machine is described in a later section.

(b) Microphone Placement for Noise

(D-1-b) Control Measurements: Many measurements that are made for noise control purposes require that the microphone be placed to measure reverberant levels (levels which include reflected sound from walls, etc.) rather than direct levels which are obtained relatively close to machinery. The following remarks are therefore made in this connection.

The noise at any place in a machinery room gets there along a direct path from the one or more radiating areas and also along indirect paths of reflections from the ceiling, walls, and other objects. In a small room or enclosed space, the reverberant levels due to reflected sound will generally be relatively high. In a very large, high-ceiling room or relatively open space such as out in the open most of the sound will be the direct path energy and there may be only little reflected sound. The reduction in the direct sound is about 6 db each time the distance from the source is doubled while the reverberant sound is fairly constant throughout the space.

In the most common machine rooms if it is desired to measure general noise conditions including reverberation or reflection effects, then the microphone distance should be relatively great, say about 10 to 20 feet. If only the direct sound is wanted, however, then a distance such as 1 to 5 feet may be more suitable, or possibly greater if the machine is unusually large and the ceiling and walls are farther away than usual. Common distances suggested by the standards[5,12] are 1, 3 or 10 feet. The purpose of the measurement, therefore, will dictate the distance.

In making measurements out of doors or in very large enclosed spaces, the same considerations apply generally except that there is little or no reflection from ceil-

(D-1-b) ing and walls, and measurements at a great distance are smaller for the same distance when measured inside of a room.

There are cases where it is not possible to use the microphone at a certain desirable distance because of background or other machine noise. In these cases an extremely short distance may be required, and directional and proximity effects should be carefully considered.

(c) Microphone Techniques for Special Conditions: There are a number of special conditions concerning microphone techniques and several of the more important of these are described here. The microphone should not be placed in strong air currents such as exist in ventilation ducts or outlets, since readings taken under such conditions are due to air motion effects on the microphone element and are false indications.

These difficulties also occur in making measurements out of doors in the wind. Such troubles will usually be indicated by much greater fluctuations in the overall level shown on the meter than those heard by ear. The equipment may often be used under slight wind conditions, however, if a wind screen is placed around the microphone. Such a shield can be made with a ten-inch diameter spherical framework of stiff wire covered with muslin.[2] A second, somewhat larger shield around the first may be helpful in extreme cases.

In localizing noise radiators in a large machine or other noise source, it may be desirable to use a directional microphone rather than the one supplied with the sound meter. Since such microphones respond to sound in one direction, the technique is simply to orient the microphone for maximum meter indication. Readings of the meter will not be accurate, however, when a different micro-

(D-1-c) phone than the one supplied is used. This technique often requires a pair of headphones plugged in the meter output jack.

In extremely large and complex sources such as those identified with oil refineries and similar plants, the main radiating surfaces may be difficult to localize. In such cases the microphone may be inserted in a megaphone or similar horn with good results. Again, headphones plugged into the sound meter will assist in localizing. As before, the sound meter readings will indicate relative sound pressure level.

For small sources a physician's stethoscope often is useful in localizing noise sources and is worthy of mention here.

Another special condition should be mentioned here. There are many cases of equipment mounted on compliant wood floors or walls. The floor or wall in such cases is likely to emit a considerable portion of the total noise. Since the total noise is usually of interest, measurements are made in the usual way as described earlier. If the noise of the machine alone is wanted for such purposes as control of noise, it should be isolated from the floor or wall with vibration mountings so that no floor or wall noise radiation results.

For most industrial noise measurements the orientation of the microphone is important, but if the measuring equipment is used in the usual way, the microphone will be oriented properly. The instrument calibration is based on random incidence upon the sensitive element of the microphone. In most noise conditions the sound paths are random. In cases of noise measured only a few feet from ordinary sources or noise coming from one direction, it is necessary to make arrangements so that the sound path is toward the side of the microphone.

2. Standing Waves and Reflections:

(D-2) When the noise being measured consists of one or more pitched tones and when adjacent walls and a ceiling surround the source, it is a rather common experience to hear the variation in intensity due to standing wave or pattern effects upon slight movement of the head. This also is true with some complex noises when the radiating area or some reflecting surface on or near the machine focuses the noise energy. Measurements under such conditions must be compensated by an averaging technique or treated in some way to recognize peak and minimum values.

Such effects generally are not encountered in machinery noise of complex nature, but do occur with very high speed machinery or equipment with components operating at high vibrational speeds such as sirens, horns, and other sources emitting pitched noises.

3. Effect of Background Noise: In most industries the sound measured near a single machine is the noise of that machine combined with the background noise. For most purposes it is desirable to measure the total noise since it is this condition to which personnel are exposed. Under these conditions the measurements are as read.

For some noise control purposes, however, the noise of a single machine operating in a noisy background often is desired. In these cases, measurements generally are made relatively close to the machine and its noise must be separated from the background by means of a correction. This correction is described here.

Generally, if the noise at a machine being measured is 10 db above the background (in octave bands) when the machine is off, then the background level can be disregarded. If there is no increase in the indicated level when the machine being investigated is turned on, then its level is below the background and cannot be measured under the existing condition.

(D-3) If the octave level is increased when the machine is on, but is less than 10 db above the background, then a correction can be applied to the indicated level of background and machine noise. The following table shows the required correction:

TABLE III.
CORRECTION FOR BACKGROUND SOUND PRESSURE LEVELS

Difference between Octave Levels of Background and Machine, and Background Alone, db	Db to be Subtracted from Octave Levels of Background and Machine Noise
1	7
2	4.3
3	3
4	2.2
5	1.7
6	1.3
8	0.8
10	0.4
over 10	0

As an example, if the combination of background and machine noise has a level of 84 db in an octave band and the level for the background alone is 80 db, then the correction of 2.2 db (corresponding to the 4 db difference) must be subtracted from the 84 db, resulting in a level of 81.8. For practical purposes the machine noise alone can be considered as 82 db.

4. Auxiliary Equipment: There are many instruments which may be considered as auxiliaries to the sound level meter. Such auxiliaries may be used to obtain permanent records or to permit an average to be determined from varying levels. They are also useful in counting or determining the characteristics of cyclical noise conditions.

(a) Recording Instruments: Various instruments are available for recording the output of the sound level meter or analyzer. The two most important are magnetic recorders and graphic level recorders. The magnetic recorder is becoming increasingly valuable as a tool. It permits a recording made in the field to be reproduced for analysis at a later time. Such a recording can be used for fre-

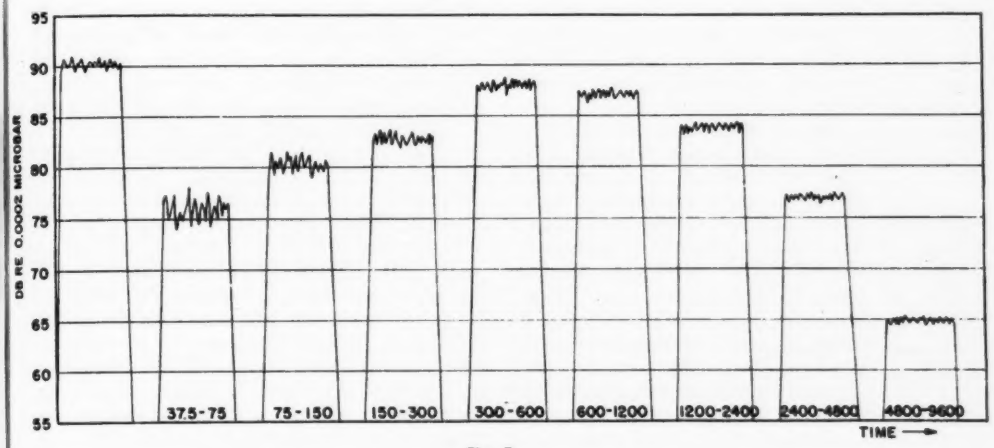


Fig. 7.
Octave levels of a typical industrial noise with relatively broad-band characteristics.

(D-4-a) quency analysis, counting, timing, and other purposes. A typical technique is illustrated in Fig. 5, where a magnetic recording is being analyzed. The magnetic recorder is shown by the two lower units at the left. The recording is on a tape loop running through the recorder and the loop mechanism shown above at the left.

Details of these techniques are beyond the scope of this report, but equipment instructions often cover such cases and the manufacturer usually can supply further information. A narrow band analyzer (Table II, number 10) shown at the right is used to determine the frequencies and corresponding amplitudes of the recorded noise.

The paper chart type of recorder is used when a permanent visual record is desirable or when a record over a period of time, possibly an average, is wanted. For some purposes it is necessary for the chart recorder to follow rapid sound level changes and in such cases special equipment with a rapid movement stylus is necessary.

Fig. 6 shows the sound level meter, sound analyzer (center)

(D-4-a) (Table II, numbers 1b and 10) and graphic level recorder (right) used in an arrangement to record relative levels at various frequencies. The microphone is located at a distance and the cable can be seen connected at the upper right corner of the sound meter. Fig. 7 shows typical octave levels of an industrial noise with relatively broad-band characteristics. These were taken with a recording arrangement such as in Fig. 6, except that an octave analyzer was used in place of the narrow band analyzer shown.

(b) The Cathode Ray Oscilloscope: The cathode ray oscilloscope may be connected to the sound meter output circuit to indicate the sound pressure level on the screen. A useful technique is to employ the cathode ray oscilloscope as a peak reading instrument to indicate noise peaks. The sound level meter needle cannot follow steep sound pressure rises which characterize impact noises, but the oscilloscope often will indicate these. Calibration of the screen, therefore, will permit a better evaluation of such peaks than the sound meter can provide. With sufficient experience the technician can use

(D-4-b) the oscilloscope for rough analysis. Observation of such traces becomes a more valuable technique as the enginer becomes experienced.

(c) Headphones: The engineer who does much sound measurement, especially around equipment with which he is not familiar, should use a pair of headphones. These have been mentioned in the earlier section, "Use of Sound Measuring Equipment in the Field," where it is pointed out that the inexperienced technician should use headphones. The sound heard in the headphones should be the same as that heard without the headphones. In this way false readings due to hum from magnetic fields and arcing due to electrical contacts will be detected.

(d) Vibration Measuring Instruments: An instrument for indicating the acceleration, velocity, or amplitude of machine parts may not be considered as noise measuring equipment. However, the vibration meter often is valuable in supplying additional information such as the location of radiating areas. Overall vibration without respect to frequency is indicated by this meter.

The pickup for this instrument has for its active element either a Rochelle Salt crystal or a coil of wire which moves in a magnetic field. In use, the pickup is held against the vibrating part. Just as the sound level meter should be used with an analyzer, the vibration meter also should be used with an analyzer. Vibration analyzers are supplied which may be connected to the output of the vibration meter.

IV. The Calculation of Loudness of Broad-Band Noise

IN MOST CASES of industrial noise measment, octave band data yield sufficient information about the noise. From these data, one can describe with fair accuracy the effect of noise on speech, the loudness of the noise, and probably when sufficient data are available, the extent of its damage to hearing. In many problems where control and reduction of noise are involved, it is advantageous to represent the noise by a single number. In such cases, the loudness of the noise is an important characteristic. In the paragraphs which follow, a technique for calculating the loudness of a broad-band noise is described.

The calculation of loudness of broad-band noise previously referred to is of sufficient importance in industrial noise to justify description in a section by itself. Complete information must be obtained from the original literature.[2,9,10] However, a working knowledge is presented here in such form that the acoustical worker can evaluate loudness from the octave levels.

A chart shown in Fig. 8 facilitates the computation. For the moment the curves of noise data plotted on the chart should be disregarded. The vertical scale at the left is the loudness in sones. This unit was described earlier. The vertical scale at the right is the loudness level in phons. The use of phons for loudness level has been employed as a loudness indication in the past but is not used generally. The relation between sones and phons can be seen from the figure.

At equally spaced intervals along the abscissa are shown octave bands covering the audible spectrum and used in currently available octave analyzers. On this gridwork of lines are drawn the curves corresponding to equal sound pressure levels in octave bands. Thus a level of 70 db in the 150-300 cps band corresponds to a loudness of 6 sones, one of 70 db in the 600-1200 cps band has a loudness of 10 sones, and a level of 70 db in the 2400-4800 cps band has a loudness of 15 sones. It can be seen that the loudness in the 2400-4800 cps band is very high compared to loudness at equal sound pressure levels at lower or higher frequencies. Intense noise in bands at low frequencies (which usually produce high overall levels), therefore, has low loudness figures. This chart is useful in showing those frequencies which are important to loudness as judged by the ear.

The loudness in sones for each band is read from the scale at the left. These individual octave band loudnesses are added

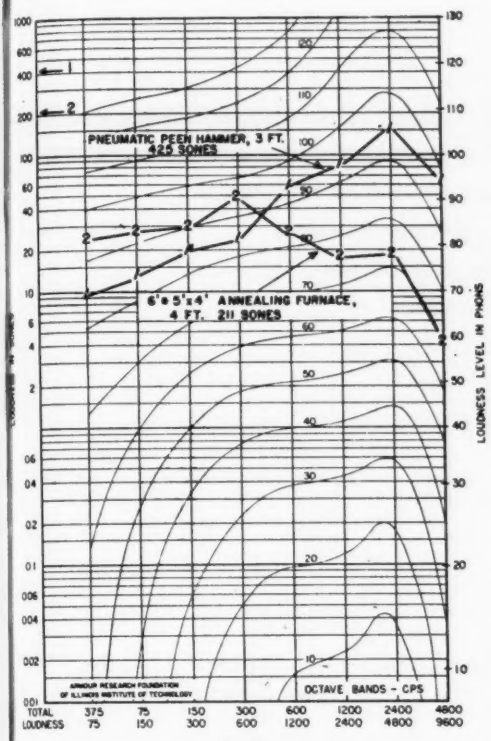

PNEUMATIC PEEN HAMMER, 3 FT.
425 SONES
6"x5"x4" ANNEALING FURNACE,
4 FT. 211 SONES
LOUDNESS LEVEL IN PHONS
OCTAVE BANDS - CPS
TOTAL LOUDNESS
375 75 150 300 600 1200 2400 4800
75 150 300 600 1200 2400 4800 9600

Fig. 8.
A chart for calculating loudness. The octave band levels from Fig. 4 are plotted on this graph to obtain total loudness.

arithmetically, the sum being the total loudness. The convenience of being able to add octave band loudnesses to obtain the total loudness by means of such a chart can easily be seen.

The two curves of data shown in Fig. 8 illustrate the loudness calculation. The two analyses presented in Fig 8 also were chosen to emphasize the value of the loudness figures over the overall levels. It can be seen that the loudnesses of 425 and 211 for these two sources are in the ratio of two to one. These loudness values confirm the ear evaluation that one is about twice as loud as the other. When it is realized that both noises had overall levels of 102 db, the value of the loudness figure is better appreciated.

Fig. 9 is a list of typical noise sources with their overall sound pressure levels and loudnesses. The heavy horizontal lines are proportional to the loudnesses. The loudnesses in sones provide much better relative evaluation of the noise than the overall levels. This is even more convincing to the acoustician who has heard and measured many of these noises.

V. A Typical Measurement Procedure

IN PREPARING this article it was felt that newness of the material and the many details presented would leave the technician of little acoustical experience with a helpless feeling regarding how to make measurements. This section has been supplied to describe a routine measurement procedure made with the purpose of obtaining permissible noise levels and information for noise control

A. ARRANGEMENT OF EQUIPMENT: Figs. 2 and 3 may be referred to again. Each of these photographs shows a standard sound level meter and its analyzer set up near noise sources that are typical of industrial equipment.

The first of these two photographs shows the Western Electric RA 358 Sound Level Meter and the RA 360 Analyzer set up to measure noise of a cut-off saw. The second shows the General Radio Type 759A Sound Level Meter and the Type 1550 Octave Band Analyzer from left to right. (Note from Table II that some of this equipment is now superseded.) The microphone is shown about two feet from the noise source in Fig. 2 and about four feet from the engine in Fig 3. In Fig. 3 the microphone was used on a relatively short cable for which no correction was needed. Although the instruments were relatively close to the noise source, they were not so close that airborne vibration caused microphonics.

Detailed information on specific equipment manipulation is not necessary here since the manufacturer's literature indicates proper procedure. When the equipment had warmed up for a few minutes, the usual calibration procedure suggested in the instructions was followed. The Western Electric equipment shown in Fig. 2 does not require external voltage for this. (The General Radio equipment is connected

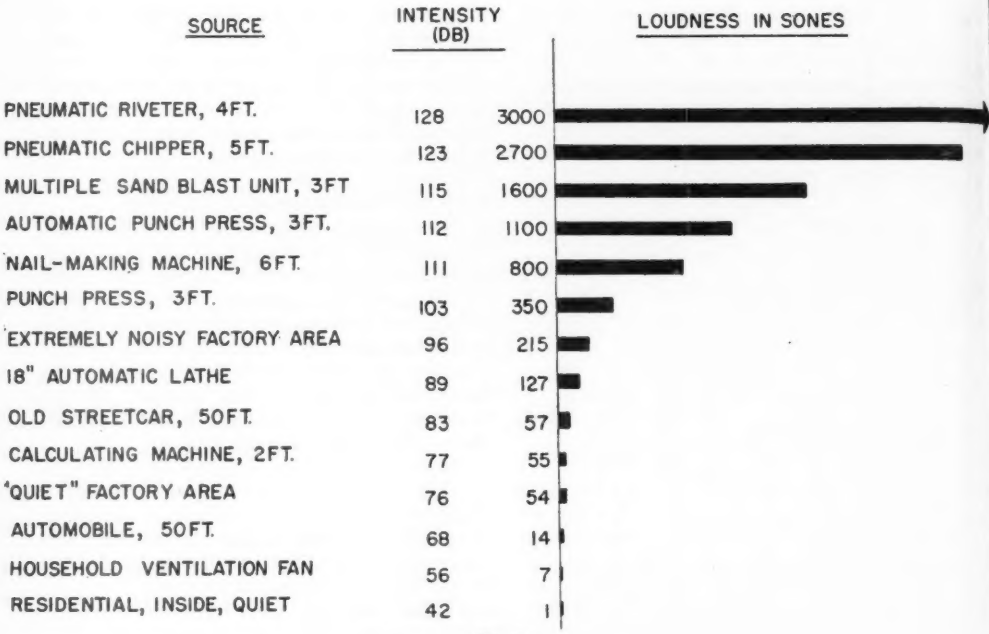

SOURCE
INTENSITY (DB)
LOUDNESS IN SONES
PNEUMATIC RIVETER, 4FT. 128 3000
PNEUMATIC CHIPPER, 5FT. 123 2700
MULTIPLE SAND BLAST UNIT, 3FT 115 1600
AUTOMATIC PUNCH PRESS, 3FT. 112 1100
NAIL-MAKING MACHINE, 6FT. 111 800
PUNCH PRESS, 3FT. 103 350
EXTREMELY NOISY FACTORY AREA 96 215
18" AUTOMATIC LATHE 89 127
OLD STREETCAR, 50FT. 83 57
CALCULATING MACHINE, 2FT. 77 55
"QUIET" FACTORY AREA 76 54
AUTOMOBILE, 50FT. 68 14
HOUSEHOLD VENTILATION FAN 56 7
RESIDENTIAL, INSIDE, QUIET 42 1

Fig. 9.
Loudness of typical industrial noises.

(A) to the 110 volt, 60 cycle line for calibration.) Both the sound level meter and the analyzer were calibrated together by this procedure. Since both instruments were in use several years, they had been given overall calibrations described under (c) in the earlier section on calibration.

Referring now to measurements taken as shown in Fig. 2, sound pressure levels only at this one position were measured, since noise conditions to which the operator is exposed were of interest. Careful listening at the position shown indicated that the greater part of the noise at most frequencies came from this noise source when it was being used rather than from others in the area. This conclusion was confirmed by turning off the saw and making measurements of the background at the same location. Although it would be more satisfactory for measuring the noise source alone to have the background levels of 10 db below levels with the saw operating, this was not possible.

(A) Furthermore, the existing condition afforded opportunity to show background corrections for this condition. In making such measurements in the field, however, it is not always possible to stop a machine to measure background levels. The noise emitted by this machine while cutting was the usual type made by a circular saw, consisting of a whine and wide-band noises of teeth cutting wood. There were no transient impact sounds occurring to make sound pressure level measurement difficult.

While watching the meter needle, the measuring equipment was lifted by hand from the table on which it rested. This was done in several bands to be sure that vibration transmitted through the table did not affect readings. Had the meter needle indicated lower levels when the instruments were lifted, this would show that such vibration was causing high readings.

B. MEASUREMENTS AND COMPUTATIONS: Readings and computations are shown on the suggested data sheet shown in

ABC MACHINE AND TOOL COMPANY

NOISE LEVEL DATA SHEET

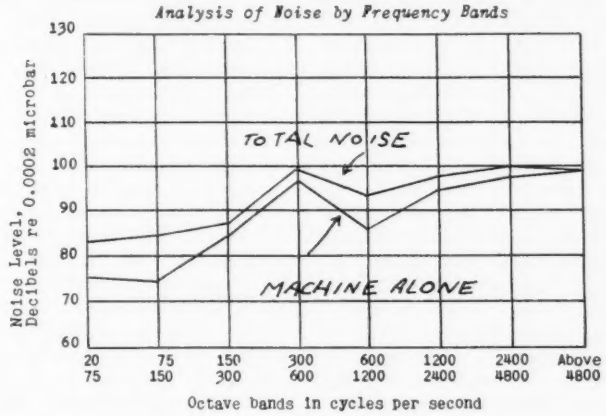
Date 2-12-52 Time 2:00 P.M. Data by F.H., G.B.

Equipment Cut-off saw, Supreme Machy Co., Mod. B. Conditions Microphone: 2 ft Operator: 2 ft

Sound Measuring Equipment RA358SLH RA360 Octave Filter (Western Electric)

		Octave Levels 20–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	Above 4800
Original Readings	1. Total Noise	83	84	88	102	94	99	101	97
	2. Background Noise	83	84	85	94	93	94	96	76
	3. Calibration Correction	+2	+1	0	-2	0	-1	-1	+4
Corrected Data	4. Total Noise (Line 1 + line 3)	85	85	88	100	94	98	100	100
	5. Background Noise (Line 2 + line 3)	85	85	85	96	93	93	95	80
	6. Total minus Background (Line 4 - line 5)	0	0	3	4	1	5	5	20
	7. Background Corrections (From Table III)	*	*	3	2	7	2	2	0
	8. Levels of Machine Alone (Line 4 - line 7)	75	75	85	98	87	96	98	100

* Since the level with the machine running is not above the background level for these octave bands, the level of the machine alone cannot be computed. It may be assumed to be more than 10 db below the background, and its level is estimated to be about 75 db or less.



REMARKS (EXPOSURE TIME, ETC)

Operator exposed about one-half hour in ten second periods each eight-hour day.

Fig. 10.
Suggested data sheet for sound measurements.

(B) Fig. 10. The original meter readings of the total noise are logged on line 1. Where permissible levels are of interest no further meaurement data are required. Noise source and microphone position information should be logged in the space provided at the top of the sheet. Remarks on the exposure conditions are very important and should be carefully noted and added at the bottom of the sheet. The overall calibration corrections of line 3 are added to the readings of line 1 resulting in the corrected total noise data of line 4. These are the final data and are plotted as the upper curve in the chart.

When information is wanted for noise control purposes, the noise levels of the source itself are necessary. The background noise data with the noise source turned off should be taken and logged on line 2.

To show the use of background corrections as explained in conjunction with Table III in Section III, the computations have been carried out as indicated in lines 6, 7, and 8 on the data sheet. The background noise is subtracted from the total noise (line 4 minus line 5), and the result is given in line 6. From Table III the corrections are obtained for the figures in line 6, and are given in line 7. These corrections are subtracted from the total noise figures in line 4 with the resulting values shown in line 8. These octave band levels in line 8 are the noise levels for the saw alone, that is, with no background noise, and are plotted as the lower curve in the graph.

There are cases where care is required in applying the corrections of Table III. These involve measurements where the total noise is only about 1 db higher than the background. In general, industrial noises cannot be measured more accurately than 1 db. Table III indicates a correction of 7 db for a 1 db difference. Differences of 1 db, and even 2 db (with a correction of 4 db), between the total noise and background noise should be examined carefully before applying the related corrections and viewing the resulting levels with confidence.

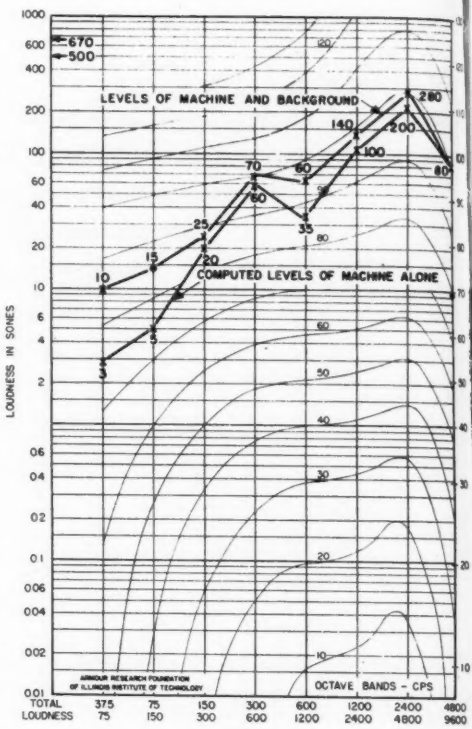

LEVELS OF MACHINE AND BACKGROUND
COMPUTED LEVELS OF MACHINE ALONE
LOUDNESS IN SONES
ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY
OCTAVE BANDS - CPS
TOTAL LOUDNESS
375 75 150 300 600 1200 2400 4800
75 150 300 600 1200 2400 4800 9600

Fig. 11.
Loudness of cut-off saw.

C. INTERPRETATION: These data can be plotted simply as levels in octave bands, as shown in the chart of Fig. 10, or they can be plotted to obtain the loudness if desired. Since these tabulated data refer to the noise of the machine alone and also to the total noise of machine and background, the question arises as to which set of data is of interest. The workman is exposed to the combined noise of the one machine and of others in the area, hence in considering possible damage to his ears, line 4 should be considered rather than line 8. In this particular case, the two sets of data are not much different.

In Fig. 11 both sets of data are plotted to obtain the loudnesses of the two conditions. The loudness in sones for each octave level appears near the curve for each octave band. The total loudness is the simple arithmetic sum-

(C) mation of these loudnesses. This addition results in a total loudness of about 500 sones for the machine alone and about 670 for the machine and the background.

The loudness figures of 500 and 670 sones can be compared with other sources mentioned in Fig. 9.

VI. Conclusion

INDUSTRIAL NOISES can be measured with available equipment using techniques which have proved to be satisfactory. The procedures involve making measurements in places where workers are exposed to noises, taking care to pay attention to exposure conditions. The readings are made in decibels in the various octave bands since these appear to have better correlation with industrial deafness than other types of analyses.

Since this material was prepared for the safety engineer,[14] the industrial hygienist, and other plant personnel to whom the measuring equipment and techniques are new, it has become necessary to point out the new methods, their shortcomings and necessary precautions in their use. It is hoped that this material will assist these workers in techniques of noise measurement and interpretation.

The author wishes to acknowledge the assistance of Dr. H. C. Hardy, Assistant Chairman, Physics Research Department, D. B. Callaway, Supervisor, Sound and Vibration Control Section, and F. G. Tyzzer, Senior Physicist, Armour Research Foundation of Illinois Institute of Technology.

References

1. American Standard Acoustical Terminology, Z24.1-1951, American Standards Association.
2. BERANEK, L. L.: Acoustic Measurements. John Wiley and Sons, 1949.
3. MORSE, P. M.: Vibration and Sound. McGraw-Hill, 1936.
4. OLSON, H. F.: Elements of Acoustical Engineering. Van Nostrand, 1947.
5. American Standard for Noise Measurement, Z24.2-1942, American Standards Association.
6. STEVENS, S. S. and DAVIS, H.: Hearing, Its Psychology and Physiology. John Wiley and Sons, New York, 1938.
7. Sound Level Meters for Measurement of Noise and Other Sources, Z24.3-1944, American Standards Association.
8. BERANEK, L. L.: Apparatus for Noise Measurement. Proceedings of the National Noise Abatement Symposium, Chicago, Illinois, October 20, 1950.
9. BERANEK, L. L., MARSHALL, J. L., CUDWORTH, A. L., and PETERSON, A. P. G.: The Calculation and Measurement of the Loudness of Sounds. *J. Acoust. Soc. Am.*, 23:261 (1951).
10. MINTZ, F., and TYZZER, F. G.: A Loudness Chart for Octave-Band Data on Complex Sounds. *J. Acoust. Soc. Am.*, January, 1952.
11. SCOTT, H. H.: The Degenerative Sound Analyzer. *J. Acoust. Soc. Am.*, 11:2 (October) 1949.
12. American Standard Test Code for Apparatus Noise Measurement, Z 24.7-1950, American Standards Association.
13. Sound Measurement Test Code for Centrifugal and Axial Fans, National Association of Fan Manufacturers, 1942.
14. Noise: Causes, Effects, Measurement, Costs, Control. School of Public Health, The University of Michigan, 1952.

Conference on Industrial Health

THE FIFTH ANNUAL Gulf Coast Regional Conference on Industrial Health will be held at the Rice Hotel, Houston, Texas, September 24-27, 1952. The program is designed to appeal to industrial management interested in personnel, health, medical, nursing and safety services. As the principal theme, the transportation industry will be highlighted.

The evening of September 24 will be devoted to a program on alcoholism. September 25th will feature a symposium on industrial wastes. The following days will be devoted to panels on various subjects related to industrial health.

Problems in the Analysis of

URINARY COPROPORPHYRIN III

By
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Kettering Laboratory, Department of Preventive Medicine and Industrial Health, College of Medicine, University of Cincinnati.

THE CORRELATION between the urinary excretion of coproporphyrin III and lead absorption has been the subject of a number of reports in the past few years.[3-17] Determinations of coproporphyrin I and III have been made by semi-quantitative methods[4-16] during a period in which techniques and interpretations were in the pioneering stage. As a result reliable quantitative relationships have not been established.

It is evident that some relationship exists between the quantity of coproporphyrin III and that of lead in the urine in bona fide cases of lead intoxication.[4,5,6,8] Large quantities of coproporphyrin III may be found in the urine in cases of lead poisoning, as illustrated by the data obtained on two cases studied in this Laboratory (Figs. 1 and 2). In both cases, the quantities of lead present in the urine and blood were within the ranges of concentration frequently associated with the occurrence of lead intoxication. The coproporphyrin values were 20-fold as compared with the quantities judged to be normal by Watson,[17] and 10-fold as compared with normal values described later in this report.

The value of the determination of coproporphyrin in borderline cases or as a measure of early absorption is unknown and requires further study involving the establishment of accurate normal base levels by the use of precise and specific analytical methods. With this in mind, the analytical method has been investigated to determine the various factors which affect accuracy and specificity of analysis. Certain factors of importance are outlined point by point in the following paragraphs.

Presented at the Thirteenth Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, Cincinnati, Ohio, April 21-25, 1952.

Analytical Factors

THE ANALYTICAL method employed in connection with these observations was essentially that of Schwartz and co-authors. It employs the iodine wash to include porphyrin precursors.[1,2] The quantity of porphyrin extracted by this procedure is measured by means of a sensitive filter fluorimeter in which the characteristic fluorescence excited by radiations at 400 mμ. is measured at 595 mμ. Analyses based on the absorption of energy at 402 mμ. have also been used to check the determinations made by measurement of fluorescence. The agreement between the two types of measurement is evident from Table I. Either method of measurement, therefore, may be used to determine the porphyrin content of urine extracted by the procedure referred to above.[1] A modification involving the use of 0.58 N (2%) HCl in place of the 1.5 N (5%) HCl proposed by Schwartz[1] has been introduced to increase the efficiency of the extraction procedure. The reason for the revision is illustrated by the data given in Figs. 3 and 4. Fig. 3 shows the improvement in the recoveries of coproporphyrin when extracted with 1-3% HCl solution, while Fig. 4 shows the increased sta-

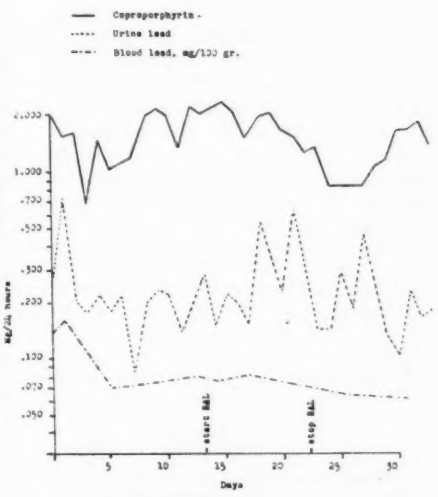

Fig. 1.
Relationship between urinary coproporphyrin and the quantities of lead in the urine and blood of a person suffering from lead intoxication. Case L.

bility of the coproporphyrin in 2% acid. The latter point is important for maintaining the reference standards over long periods of time. The modified extraction method, therefore, is satisfactory for determining absolute quantities of coproporphyrin I or III.

Preservation

THE POSSIBILITY of obtaining true quantitative data depends upon the proper collection and preservation of the urinary samples. In our hands the use of sodium carbonate as a preservative for coproporphyrin as advocated by Schwartz[1] was effective if the limitations were known, but was far from ideal when applied to samples taken for lead analysis as well.

Some of the limitations are as follows:

(a) Errors in anticipating the extent of the acidity and the ultimate volume of urine in the 24-hour period make it difficult to estimate the quantity of sodium carbonate to be added. Our experience suggests the need for 25 grams per liter of anticipated urine if stability is to be maintained for several days. Schwartz advocated five grams per liter.[1] (Table II.)

(b) The addition of sodium carbonate

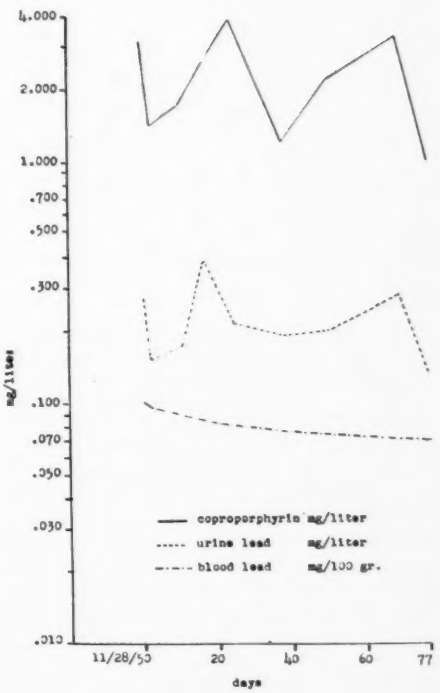

Fig. 2.
Relationship between urinary coproporphyrin and the quantities of lead in the urine and blood of a person suffering from lead intoxication. Case S.

TABLE I.
COMPARATIVE FLUOROMETRIC-SPECTROPHOTOMETRIC MEASUREMENTS

Mgs. Coproporphyrin per Liter of Urine		
Fluorometric (595 mμ.)	Spectrophotometric (402 mμ.)	Percent Difference
0.055	0.045	+18
0.055	0.050	+9
0.080	0.075	+6
0.120	0.115	+4
0.120	0.115	+4
0.145	0.150	+3
0.055	0.060	−9
0.070	0.075	−7
0.080	0.085	−6
0.130	0.135	−4
0.145	0.148	−2
0.050	0.050	0
0.055	0.055	0
0.070	0.070	0
0.090	0.090	0
0.090	0.090	0
0.120	0.120	0
0.135	0.135	0
0.150	0.150	0

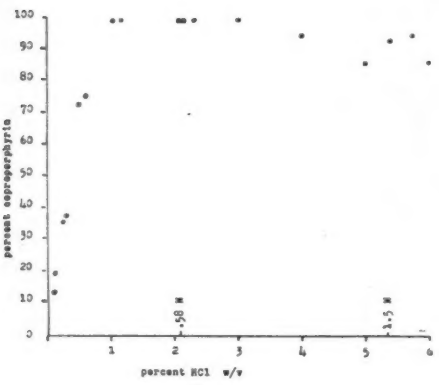

Fig. 3.
Optimum HCl concentration for extraction of porphyrin from urine.

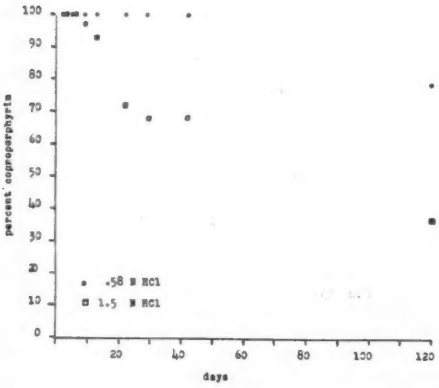

Fig. 4.
Effect of HCl concentration on the stability of extracted coproporphyrin.

appears to encourage certain microbiological effects which seem to cause an increased production of porphyrin from precursors in the urine.

(c) The precipitation of urine salts by sodium carbonate, with coprecipitation of lead and the introduction of a source of lead contamination, make it difficult to obtain reliable lead determinations.

Another material for preserving the coproporphyrin, therefore, was sought and found in ethyl acetate. However, ethyl acetate is not convenient to use with large volumes of urine, and a portion of each freshly voided sample (not more than 10 ml.) must be removed and covered with a layer of ethyl acetate and shaken lightly if full protection for 96 hours is to be obtained. The preserved sample must then be transferred in toto to a separatory funnel and subjected to the extraction procedure of Schwartz with the modifications described above. The superiority of ethyl acetate for preserving coproporphyrin is illustrated by the data in Table II.

TABLE II.
STABILITY OF URINARY COPROPORPHYRIN IN THE PRESENCE OF SODIUM CARBONATE AND ETHYL ACETATE

Percent Sodium Carbonate	Percentages of Coproporphyrin Recovered from Urine after Standing			
	24 hr.	48 hr.	72 hr.	96 hr.
0.5	76	63	62	63
1.0	89	78	86	56
1.5	80	73	75	54
5.0	100	95	85	58
		Ethyl Acetate		
	100	100	100	100
		Untreated		
	70	69	62	50

Normal Values

INTERPRETATION of the urinary coproporphyrin results must be based upon the range of the concentration of coproporphyrin in the urines of persons who have not been exposed to unusual quantities of lead and are in a good state of health. The values obtained by the analysis of fresh spot samples of the urine of healthy unexposed persons are tabulated in Table III. This table shows the frequencies of occurrence of varied quantities of coproporphyrin.

TABLE III.
DISTRIBUTION OF PORPHYRIN IN SPOT SAMPLES OF THE URINE OF INDIVIDUALS WHOSE EXPOSURE TO LEAD WAS NOT UNUSUAL

Mg/Liter	Men	Women
0.000-0.039	1	1
0.040-0.059	0	6
0.060-0.079	0	6
0.080-0.099	4	5
0.100-0.119	4	4
0.120-0.139	5	5
0.140-0.159	5	3
0.160-0.179	3	0
0.180-0.199	5	0
0.200-0.219	0	0
0.220-0.239	0	0
0.240-0.259	3	0
Number of Samples	30	30
Mean	0.168	0.101
Standard Deviation	±0.050	±0.037

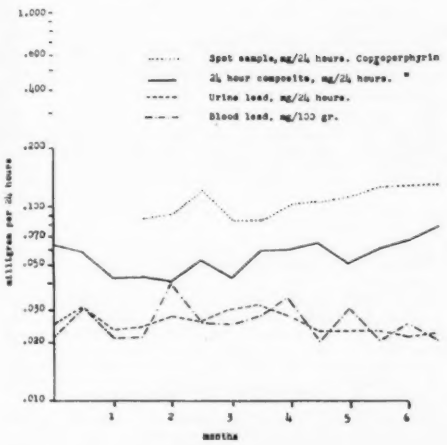

Fig. 5.
Relationship between the quantities of coproporphyrin in preserved spot urine samples and 24-hour unpreserved specimens of urine. Case of FC non-exposed.

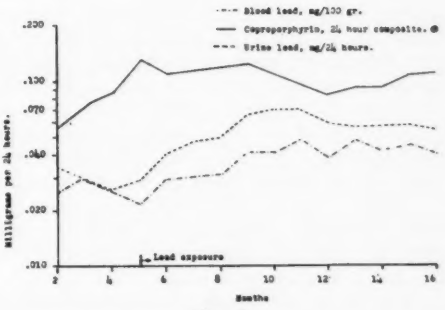

Fig. 6.
Relationship between the quantities of coproporphyrin in the urine and the quantities of lead in the urine and blood. Case MB exposed to 0.075 Mg. Pb/M³.

phyrin in such samples of urine. The range of concentration was approximately 0.04-0.26 for men and 0.04-0.16 for women. The mean values were 0.101 mg/liter and 0.168 mg/liter respectively for the women and men included in these observations.

The results obtained during a continuous study of a single normal healthy experimental subject, who had never been exposed to unusual amounts of lead, are shown in Fig. 5. In this case both 24-hour and spot samples were employed. The spot sample was a 10 ml. portion of a single voidance collected at the same hour each day and preserved with ethyl acetate. The 24-hour unpreserved sample was collected for lead analysis but was also used to study the porphyrin deterioration pattern. All values obtained from the two types of samples fall within the range of the results shown in Table III. The mean output of coproporphyrin per 24-hours, as calculated from the results of the analysis of the preserved spot samples, is approximately 100% higher than that obtained from the analysis of the unpreserved 24-hour specimens in which, no doubt, destruction of porphyrin occurred. It is evident that the analysis of a fresh or preserved spot sample of urine is a good procedure from the aspect of the avoidance of loss of coproporphyrin on allowing the sample to stand unpreserved. On the other hand, the spot sample of small volume is open to serious question from the point of view of the diurnal variability in the excretion of coproporphyrin. Such diurnal variations in the case of a single individual are illustrated in Table IV. Another individual studied in the same way gave variations between the limits +40% to −42% from the average concentration. Calculations based on the use of results obtained in analyzing a preserved spot specimen, therefore, may err to a maximum of ±30% to ±40% in expressing the daily output.

TABLE IV.
DIURNAL VARIATIONS IN URINARY CONCENTRATION OF COPROPORPHYRIN
(FC November 1915)

Time Voided	Mg/Liter during 9 days								
	1	2	3	4	5	6	7	8	9
am									
12-2									
2-4									
4-6							0.120		
6-8	0.108	0.065	0.110	0.090	0.090	0.115		0.105	0.130
8-10		0.065							
10-12	0.080		0.095	0.120	0.115	0.080	0.105	0.120	0.120
pm									
12-2	0.100	0.073		0.095	0.090	0.115	0.080	0.135	0.120
2-4		0.088	0.095	0.120					
4-6	0.095		0.120		0.115	0.135	0.150	0.165	0.165
6-8		0.080		0.105		0.105	0.095		0.115
8-10	0.080		0.080		0.080	0.150		0.105	0.080
10-12	0.105	0.080	0.110	0.115			0.115	0.105	
Average	0.095	0.075	0.102	0.108	0.098	0.117	0.111	0.123	0.122

Although large quantities of copropor-

phyrin are excreted in the urine of persons suffering from lead poisoning (Figs. 1 and 2), such dramatic changes do not occur in association with the absorption of small to moderate quantities of lead. In the course of a prolonged continuous study of an individual exposed to a lead oxide in the atmosphere, there was a mean increase of about 0.03 mg/liter of urine and a definite increase in the lead concentration in the blood. At no time was there an appreciable increase of the coproporphyrin in the urine of this individual. The quantitative relationship between lead absorption and coproporphyrin excretion in the urine needs further amplification and study. If the analysis of coproporphyrin in the urine is to be employed to detect incipient cases of lead poisoning, then it appears to be a helpful supplementary procedure. However, if the aim is to recognize potentially dangerous exposure to lead before such exposure has resulted in incipient toxic changes, its value is dubious.

References

1. SCHWARTZ, S., ZIEVE, L. and WATSON, C. J.: An Improved Method for the Determination of Urinary Coproporphyrin and an Evaluation of Factors Influencing the Analysis. *J. Lab. and Clin. Med.*, 37:843 (1951).

2. WATSON, C. J., PIMENTA DE MELLO, R., SCHWARTZ, S., HAWKINSON, V. and BOSSENMAIER, I.: Porphyrin Chromogens or Precursors in Urine, Blood, Bile and Feces. *J. Lab. and Clin. Med.*, 37:831 (1951).

3. MALOOF, C. C.: Role of Porphyrins in Occupational Diseases. I. Significance of Coproporphyrinuria in Lead Workers. *Arch. Indust. Hyg.*, 1:296 (1950).

4. WALDMAN, R. K. and SEIDEMAN, R. M.: Reliability of the Urinary Porphyrin Test for Lead Absorption. *Arch. Indust. Hyg.*, 1:290 (1950).

5. LANGEN, C. D. DE and BERG, J. A. G. TEN: Porphyrin in the Urine as a First Symptom of Lead Poisoning. *Acta Med. scandinav.*, 130:37 (1948).

6. DOBRINER, K. and RHOADS, C. P.: The Porphyrins in Health and Disease. *Physiol. Rev.*, 20:416 (1940).

7. SALOMON, K. and COWGILL, G. R.: Porphyrinuria in Lead-Poisoned Dogs. *J. Indust. Hyg. and Toxicol.*, 30:114 (1948).

8. KARK, R. and MEIKLEJOHN, A. P.: The Significance of Porphyrinuria in Lead Poisoning. *J. Clin. Investigation*, 21:91 (1942).

9. HARROLD, G. C., MEEK, S. F. and PADDEN, D. A.: A Coproporphyrin III Test as a Measure of Lead Damage. II. Considering Lead Dusts of Relatively Large Particle Size. *Arch. Indust. Hyg.* 6:24 (1952).

10. MCCORD, C. P.: The Porphyrins. The Significance of Porphyrins in Occupational Diseases. *Indust. Med.*, 20:185 (1951).

11. SEIFERT, P.: Lead Poisoning and Laboratory Findings. *Zentr. Arbeitsmed. Arbeitsschutz*, 1:99 (1951).

12. BROOKS, A. L.: An Appraisal of a Urinary Porphyrin Test in Detection of Lead Absorption. *Indust. Med.*, 20:390 (1951).

13. BERG, E.: The Diagnosis of Early Lead Poisoning in Industrial Medicine. Dissertation, Copenhagen, 1941 (in Danish). *Biol. Abstr.*, 25:33898 (1951).

14. JOHNSON, W. S. and WHITMAN, N. E.: Coproporphyrinuria as an Index of Lead Absorption. *Arch. Indust. Hyg.*, 2:170 (1950).

15. BASTOS, R., PIMENTA DE MELLO, R. and CRUZ, W. O.: Urinary Excretion of Coproporphyrin from Workers Handling Lead. *Mem. Inst. Oswaldo Cruz*, 47: 211 (1950); C. A. 45:2117i (1951).

16. BECARES, C.: A Study of the Early Diagnosis of Industrial Lead Poisoning. *Rev. san. e hig. Pub.*, 22:677 (1948); *Bull. Hyg.* 25:1149 (1950).

17. WATSON, C. J. and LARSON, E. A.: The Urinary Coproporphyrins in Health and Disease. *Physiol. Rev.*, 27:478 (1947).

Acknowledgment to the Subcommittee

THE ARTICLE "A Rational Approach to Air Pollution Legislation" which appeared in the June, 1952 issue of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION Quarterly, listed GEORGE E. BEST, Mutual Chemical Corporation of America, as the author. This article was prepared by the Subcommittee on Legislation Principles of the Air Pollution Abatement Committee of the Manufacturing Chemists' Association, Inc., Washington, D.C. The Subcommittee was composed as follows: GEORGE E. BEST, Chairman; Mutual Chemical Company of America; CHARLES H. BUNN, JR., Standard Oil Development Company; CARL A. GOSLINE, E. I. du Pont de Nemours & Co., Inc.; DUDLEY A. IRWIN, M.D., Aluminum Company of America; and FRANK L. SEAMANS, Aluminum Company of America.

Coproporphyrin Determination *and* Urinary Lead Relationship

Experiences in an Industrial Hygiene Laboratory

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IN 1932, DR. LUDWIG HEILMEYER,[1] Germany, discussed earlier work of Dr. Hans Fischer on the determination of the coproporphyrin of urine and its clinical significance. He stated that urinary porphyrins are normally in such small quantities in the urine that they have no appreciable effect on its color. The occurrence of these iron-free products of blood pigment were recognized clinically as an important symptom of chronic poisoning from lead and/or from hypnotics, such as luminal, sulfonal, medinal, etc. According to Heilmeyer, the coproporphyrin could be separated from the urinary porphyrin by extraction in ether, since the latter compounds are soluble only in caustic and strong acids. In 1947, Watson and Larson,[2] published a comprehensive report on this subject.

C. D. deLangen and J. A. G. ten Berg[3] state that the presence of porphyrins in the urine is the first sign of lead absorption and development of poisoning. We were not interested in the excretion of porphyrin as a clinical symptom but as a rapid-screening method to select urine specimens that should be examined quantitatively for lead by the chemical method. Also, we thought this simple test might serve as a check for errors in the chemical determination of lead in spot samples, whether the error be due to contamination or to failure to find lead even where it was present in significant quantities.

We used the rapid and short method for freshly voided urine described by Johnson and Whitman[4] with slight modification.

Our procedure was as follows:

Pipette 5 ml of the urine into a pyrex test tube. Add six drops of glacial acetic acid and then two drops of 3% hydrogen peroxide. Add exactly 5 ml. of diethyl ether and extract the corproporphyrin by shaking the tube vigorously for two minutes. Examine the ether layer with an ultraviolet light (3660-4000A) in a dark room.* (Shield the light so that only the test tube is illuminated.)

We interpreted and recorded by number the observed fluorescence according to the following arbitrary scale used by Maloof:[5]

0—No reddish fluorescence, normal coproporphyrin concentration.

1—Faint or doubtful pink, slight increase in coproporphyrin .

2—Definite pink, moderate increase in coproporphyrin.

3—Strong pink to definite red, marked increase in coproporphyrin.

4—Deep red, heavy increase in coproporphyrin.

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* It was found necessary to remain in the dark room from five to 10 minutes for the eyes to become adjusted before duplicating results could be read. The time depended upon brightness of the laboratory from which one entered the dark room. Before discovering the importance of this fact, our results were generally high and the results were discarded for several score of samples.

In September of 1950, a program of determining coproporphyrin in all urinary samples received in the industrial hygiene laboratory was adopted. To date, 369 employees have been checked by this test. Of this group, 161 employees were subjected to some degree of lead exposure. Many of them were re-examined two or more times during this period. They were painters, lead burners, tetraethyl lead handlers, and a few others who had limited exposure to lead.

All employees who had possible methyl chloride exposure in the rubber plant were examined clinically every year. During 1952, coproporphyrin urinary tests were made on this group. Coproporphyrin increase has been listed as a sign of methyl chloride poisoning, but we suspected that our employees had little exposure and would show only minor effect, if any.

Some 132 outside workers and general employees, who were examined for other purposes, were tested by this method. This group was selected for control purposes so as to establish a base-line for coproporphyrin excretion in the general male population.

For employees having no known exposure to toxic materials, especially heavy metals, we found that 5.3% showed at least a trace of coproporphyrin by our procedure. Of this group, 2.3% showed 2 or more on our scale of excretion values.

Among the 76 employees who had potential methyl chloride exposure and from whom we expected no greater than normal coproporphyrin excretion we found one positive.

Among the 161 employees having potential lead exposures, coproporphyrin was found in 14.5% of the tests. Of the total tests, 7.5% showed a scale value of more than 2. For those individuals who excreted more than 0.12 mg. lead per liter of urine, 76.2% showed increase coproporphyrin and 42.8% had scale values of 2 or greater. For all individuals having 0.15 mg. per liter or greater urinary lead excretion, 82% showed coproporphyrin increase. For the seven individuals who had 0.16 mg. per liter or greater urinary lead, 100% showed coproporphyrin elevation.

It was noticed in general that as the urinary lead values increased, the coproporphyrin values followed. This same parallel applied as the urinary lead values decreased in those employees who were removed from lead exposure. Occasionally, we found a person without known exposure to lead who consistently showed a positive coproporphyrin throughout the period. We did not uncover an explanation for the elevated coproporphyrin excretion of persons without lead exposure.

TABLE I
COPROPORPHYRIN TEST CLASSIFIED AS TO EXPOSURE

Classification	No. of Tests	P 0	P 1	P 2	Urinary Lead Range
		%	%	%	Mg/liter
General	132	95	3	2	Not determined
Methyl Chloride	76	99	0	1	Not determined
Lead Workers					
Group 1	99	94	3	3	0.01-0.06
Group 2	45	86	11	3	0.06-0.12
Group 3	10	40	20	40	0.12-0.15
Group 4	7	0	57	43	0.15-0.20

By reference to Table I, it is seen that no test showed a color intensity of 3. This can be explained, we believe, by the relatively low urinary lead values found on this group. If the excretion of lead greater than 0.15 mg. per liter of urine is accepted as an indication of exposure to the maximum allowable concentration, our experience indicates that the coproporphyrin excretion can be used as a rapid-screening method in selection of urine specimens for chemical analysis.

We did not attempt to separate these results into classes according to the quantity or size of lead particles in the environmental atmosphere to which the individuals were exposed. Such a study has been made by Harrold.[6] Our results are based on low exposures to either relatively large particles or tetra ethyl lead.

The urinary lead findings were adjusted to a specific gravity of 1.024. Specimens were spot voidings and were usually collected in the morning as the men were reporting for work.

Our percentage of positives for the general population of workers having no known lead exposure was higher than has been reported by others.[7] If our results had been lower than others, we would have suspected loss of coproporphyrin by han-

dling or extraction. We have no explanation for these higher results, except that the climatic conditions, dieting habits, or some other condition that is peculiar to this area may influence coproporphyrin excretion.

Our experience indicates that the test for coproporphyrin in freshly voided urine can be made fairly quickly with usual equipment and reagents found in a medical laboratory, with the addition of a long wave length ultraviolet lamp. Much time might be saved with this test by screening out those samples that are low in urinary lead from those that might be high in urinary lead, where chemical tests are being made on a routine control basis and lead intoxication is not likely before the next examination. Also, the coproporphyrin test can serve as a check on chemical quantitative lead results for those few errors that happen even in the best laboratories.

References

1. HEILMEYER, LUDWIG: Spectrophotometry in Medicine. Germany, 1932. Translated by A. JORDON AND T. L. TIPPELL. London, Adam Hilger, Ltd. 1943.

2. WATSON, C. J. and LARSON, E. A.: The Urinary Coproporphyrins in Health and Disease. *Physiol. Rev.* 27:3, 1947.

3. DELANGER, C. D., and TEN BERG, J. A. G.: Porphyrin in the Urine as a First Symptom of Lead Poisoning. *Acta Medical Scandinovica*, Vol. 130 fase I, 1948.

4. JOHNSON, W. S. and WHITMAN, N. E.: Coproporphyrinuria as an Index of Lead Absorption. *Arch. Indust. Hyg. & Occup. Med.* 2:173, (August) 1950.

5. MALOOF, C. C.: Role of Coproporphyrin in Occupational Diseases. Significance of Coproporphyrin in Lead Workers. *Arch. Indust. Hyg. & Occup. Med.* 1:296, (March) 1950.

6. HARROLD, G. C.: Urinary Porphyrins in Lead Poisoning. Proceedings of the Lead Hygiene Conference. 129 (1948).

7. BROOKS, A. L.: An Appraisal of a Urinary Porphyrin Test in Detection of Lead Absorption. *Ind. Med. & Surgery*, 20:9, 390-392, 1951.

Sodium, Sodium Metal, Metallic Sodium

PROPERTIES of sodium and information on its safe handling and use are given in Chemical Safety Data Sheet SD-47, "Sodium, Sodium Metal, Metallic Sodium," published recently by the Manufacturing Chemists' Association, Inc. Among the principal precautions set forth are: (a) avoid contacts with water, (b) avoid contact with chlorinated hydrocarbons and solid carbon dioxide, (c) avoid use of fire extinguishers containing carbon tetrachloride, water or acids, (d) avoid using steam on sodium fires or for heating sodium reaction vessels, and (e) keep untrained personnel out of areas where sodium is handled. The data sheet describes authorized shipping containers for sodium, proper housing of tank cars for loading or unloading the molten metal, and recommended storage facilities.

Control of a

Multiple Source Hazard of Carbon Monoxide

GEORGE S. REICHENBACH, JR., Industrial Hygiene Engineer
Bethlehem Steel Company, Sparrows Point, Maryland
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Bethlehem Steel Company, Bethlehem, Pennsylvania

FOR EVERY ton of pig iron produced, about six tons of blast furnace gas are generated. The composition of this gas averages 27% carbon monoxide, 10% carbon dioxide, 3% hydrogen, trace of methane, and the remainder nitrogen. This mixture has a low heating value, but due to the tremendous quantities generated in the steel blast furnaces it is utilized in several different operations. One such use is as a fuel for firing large internal combustion engines used to drive blowing engines or alternating current generators.

At the Sparrows Point plant there are 28 of these engines in operation. Twelve engines operating in a tandem at 89 revolutions per minute drive 25 cycle electric generators. These engines and generators are located in a building of brick construction whose dimensions are 440 feet by 190 feet by 47 feet. The roof is of high-low bay construction. An adjacent building houses five more engines operating singly at 64 revolutions per minute and driving large blowing engines furnishing "wind" for the blast furnaces. This building is 250 feet by 80 feet by 47 feet and also is of high-low bay roof construction. The remaining nine engines also drive blowers at 64 revolutions per minute and are located in a building immediately south of the other two: it is 380 feet by 90 feet by 47 feet and of high-low bay roof construction.

Before being supplied to the engine, the blast furnace gas is cleaned to an average of 0.009 grains per cubic feet by Theisen washers. The engines driving the electric generators have a rate of gas consumption of 4,450 cubic feet per minute per engine. The engines driving compressors consume 3,200 cubic feet per minute per engine. The total consumption of blast furnace gas by these engines is in the range of 100,000 cubic feet per minute.

There are an average of 215 employees in this department with approximately 45 men working on a shift. The oldest 20 men in the department averaged 62½ years of age and had an average length of service of 20½ years.

Education to Danger

AWARENESS of the danger of blast furnace gas is at a high level among all personnel of departments which consume it. This is primarily due to the educational programs, such as the gas school, maintained by the Training Department. In addition to the gas school and other personnel training programs, routine checks of carbon monoxide concentrations are made of areas where a hazard might arise which further cultivate an awareness of the potential hazard among employees exposed.

It was found during these surveys that levels of carbon monoxide higher than desirable were occurring at times in the

generator and Number 1 and Number 2 blowing buildings. In order to determine the critical points, if any, of blast furnace gas contamination, a number of fixed sampling locations were established. Approximately 25 of these points were sampled in the buildings each day in order to help evaluate the problem. Sampling was done by means of a Carbon Monoxide Indicator, standardized daily and checked at one point daily with A National Bureau of Standards, Carbon Monoxide Detector.

Preliminary results indicated that the greatest quantities of gas were escaping from around the shafts of the engines. In order to control this escape, the enclosing hoods were sealed and a breather duct approximately 15 feet high was attached to each hood. This improved conditions but still not to the degree desired by the Medical Department.

Experiments were then run on one engine with local exhaust hoods installed over tailshafts, midshafts and crankshafts. It was found that extremely large airflows were necessary to reduce concentrations of gas to a satisfactory level. In addition the hoods increased the difficulties of maintaining satisfactory lubrication of the engines.

Since local exhaust ventilation proved impractical general ventilation was decided upon. Typical of the arrangement used is that in the electric generator building in which 350,000 cfm of air at two inches H_2O static pressure is blown into what is known as the front cellar, running the length of the long side of the building. This cellar has six openings into the rear cellar spaced approximately at the midpoints of the six pairs of gas engines. The front cellar acts as a plenum and allows an average of 57,000 cfm of air to escape to the rear cellar through each opening and then flow up around the engines and thence up through the building, exhausting through the high-low bay roof. The forced general ventilation supplied furnishes nine air changes per hour for the electric generator and Number 1 blowing building, and 10½ air changes for the Number 2 Blowing building.

This supplied air method maintained atmospheric conditions at an excellent level on the operating floor of all buildings. Some improvement was desired at the gallery level, where the engineer stands to turn-down grease cups periodically for lubrication. This problem has been eliminated by the installation of a forced feed oil lubrication system which practically eliminates the need for personnel to do any work on the engine gallery.

An index of the effectiveness of these measures is a record of all the dispensary cases from this department with symptoms that might be attributed to carbon monoxide.

1948.....30 visits
1949.....56 visits
1950..... 5 visits
1951.....11 visits (4 of these from a line repair)

Carbon Monoxide in Crane Cabs

IN EACH of the buildings there is a 50 ton crane. These cranes are used in conjunction with the maintenance gangs, and are used for both very bulky and precision lifts and lowerings. Concentrations of carbon monoxide found in the crane cabs at times were at the 100 parts per million level. It was felt that this was an unsatisfactory condition for maximum safety and efficiency.

It was decided that the best method of obtaining desired conditions was to isolate the crane cab from the atmosphere of the building.

To do this it was necessary to provide a means of supplying outside air to the cab and maintain a higher static pressure in the cab than in the building.

In cooperation with the Mechanical Department, several shop trials were made to design a collector arrangement to obtain air from a pressurized duct which would run parallel to the travel of the crane. The final collector design agreed upon consists of an orifice section 48 inches long by two inches wide at the center and pointed at the ends. This orifice travels between two inclined rubber lips at the lower apex of a pentagonal duct. These lips serve as a reverse Bunsen type valve. The air pressure in the duct forces the rubber lips together isolating the duct air from the building and only bleeding air through the orifice to the crane cab.

Figs. 1 and 2 show different views of

the installation. Fig. 3 shows details of the pressure duct.

The duct with rubber belting lips is 440 feet long. The air goes from the nozzle to a plenum under the cab floor and then is supplied through expanded metal flooring. The crane operator has a damper which allows him to vary the amount of incoming air between 400 and 1,200 cubic feet of air per minute. At the higher flow rate there are four air changes per minute through the cab. There is a constant flow of air through the cab regardless of location in the building. Electric heating is supplied to temper the incoming outside air for winter operation.

In summertime operation the cab can be held within two degrees of the outside ground level temperature. This combined with the generous design velocities at the higher level allows a satisfactory working environment.

No carbon monoxide has been found in this cab since the installation of this method of ventilation.

This assembly was checked for wear after eight months of operation and the report was as follows: "Inspection of 'zipper' this afternoon disclosed no visible deterioration of wear. Rubber lips are unscratched in area of maximum usage. Orifice piece is likewise unscratched and has obtained a mirror-like finish."

Installation of a second unit is in process in Number 1 blowing building.

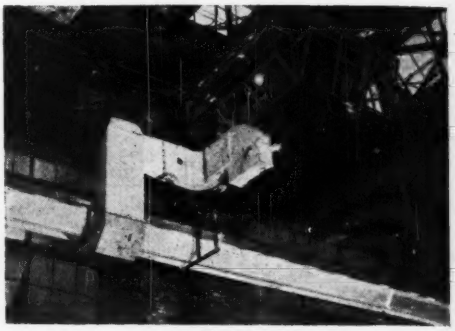

Fig. 1.

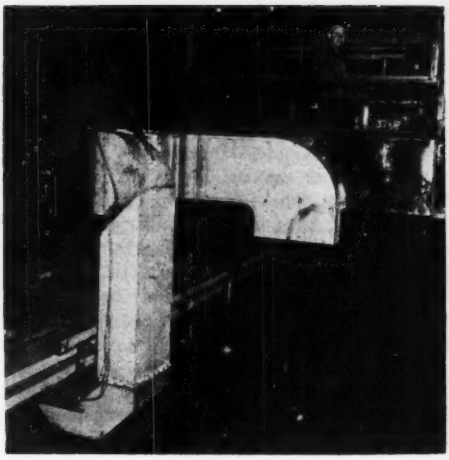

Fig. 2.

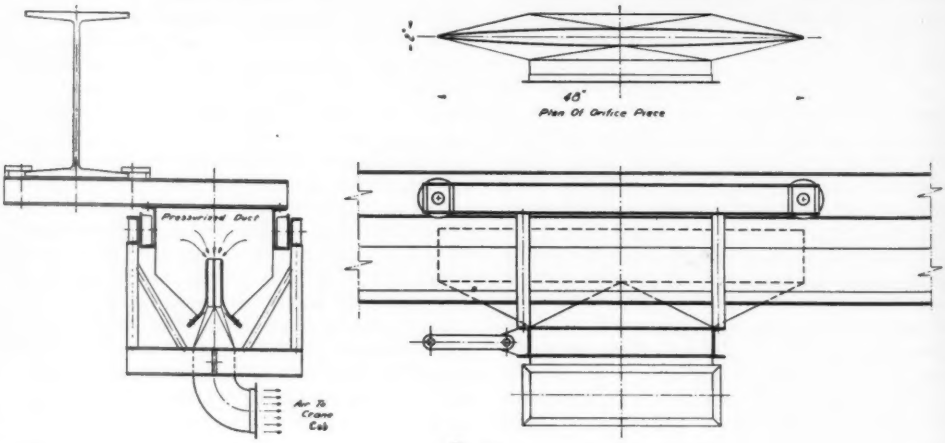

Fig. 3.

INDUSTRIAL HYGIENE BRIEFS

— An Unusual Phosphine Exposure —

STEEL BOMB bodies were immersed in a water (40 to 55%) and phosphoric acid (45 to 60%) bath to remove rust. The bath was maintained at about 170°F. and the period of immersion three to five minutes. The tank was large enough to accommodate two bomb bodies at the same time but they were immersed alternately. A copious evolution of gas occurred during the immersion. Qualitative tests for phosphine were strongly positive in the vicinity of the tank. Quantitative tests were not made. Local exhaust ventilation of the "push pull" type was applied by a vertical multiple slot hood located at the back of the tank with perforated compressed air line on the front. Further tests for phosphine were negative in the operator's breathing zone.

The operation was performed at a higher temperature than normal by about 30°F. and the concentration of the acid had been increased in an effort to secure faster removal of rust. It is believed that the elevation of temperature and/or acid concentration produced enough nascent hydrogen to reduce some of the phosphoric acid, or the slight phosphorus content of the steel to phosphine. Similar operations carried out at about 140°F. in 30% to 40% phosphoric acid have shown no indication of phosphine evolution.

Lead Exposure At Refining Operations

EXPOSURE to lead concentrations well above the maximum allowable concentration frequently exist at renovation or refinishing operations involving removal of old paint containing a lead pigment by power sanding, brushing, grinding or abrasive blasting.

About 30 atmospheric samples have been collected at such operations at about 12 plants. Concentrations of lead have ranged between 0.12 and 23.5 mg/m^3. Most concentrations of the general room atmosphere ranged from 0.24 mg/m^3 to 2.5 mg/m^3. Only one sample has shown a concentration below MAC for lead. Breathing zone concentrations are usually much higher.

Signs of lead absorption have been manifested by at least three workers exposed to such dust but active lead poisoning is not known to have occurred. Such operations could result in a chronic exposure which might result in intoxication. This is important since some such operations may be of a production line nature and involve the same personnel for long periods.

—HOLDEN B. MCCLUNG,
Army Environmental Health Laboratory

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Two industrial health engineers for university in Far West. Salary $481-$584 plus retirement program.

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The President's Page

"Every Member A Salesman"

OUR ASSOCIATION is clearly and definitely committed to sell industrial hygiene and the principles and philosophy that it embodies. We are committed in this selling to the twofold program of (1) controlling or eliminating existing undesirable and unwanted conditions in the industrial working environment that may result in employee ill health or discomfort, and (2) profiting from these accomplishments to apply preventive measures to the plans for new and future industrial processes.

Yes, control for the present—prevention for the future, that is our work together with the many related activities that this work implies. But there is more to selling industrial hygiene than in just doing our work. One needs only to look within his own horizon and see a great body of industry that has never heard of industrial hygiene —that is unaware of the causes of occupational illness or of methods to end such causes—that has not counted the economic rewards of a medical program attending the employees and their work environment.

The AMERICAN INDUSTRIAL HYGIENE ASSOCIATION is now in its fourteenth year of work with selling as the keynote for the present. Our constitution, Article II, gives us this challenge through the objectives of the association, herein restated:

1. To increase the knowledge of industrial hygiene through interchange and dissemination of information.

2. To promote the study and control of environmental factors affecting the health and well-being of industrial workers.

3. To correlate such activities as are conducted by individuals and agencies throughout industrial, educational and governmental groups.

4. To bring together persons interested in the various phases of industrial hygiene.

The AMERICAN INDUSTRIAL HYGIENE ASSOCIATION comprising, as it does, 700 scientists at work in all phases of industrial health, is an ideal group for exercising this selling opportunity. Current widespread activities in this direction on the part of our many association committees has and is now resulting in a growing awareness of Industrial Hygiene. Participation and representation in the activities of several other related professional organizations, finding candidates to enter our field, aid in establishing their educational standards, the publication of Industrial Hygiene articles in other journals and the organization of new A.I.H.A. local sections, enumerates certain of these activities.

There is a way in which each member may, as an individual, aid in this work. Each issue of our excellent journal, the *A.I.H.A. Quarterly*, carries important messages of industrial hygiene. Select a small industrial company of your acquaintance or a library in an industrial community and send them a yearly subscription to our journal.

Our *Quarterly* circulation editor, HOWARD N. SCHULZ, will be glad to acknowledge your gift subscription to the recipient. Send the gift subscription blank shown on the opposite page to the Circulation Editor. The two dollars will be spent in truly selling industrial hygiene, for who knows into what receptive hands 700 additional copies of the journal may fall every three months? And who can foresee what ideas may be stimulated toward better Industrial Hygiene?

—WILLIAM R. BRADLEY

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION

Report of the Committee on Noise

BECAUSE of the increasing interest in noise as a factor in the industrial environment and the fact that damage to the hearing mechanism produced by noise is being considered as an occupational disease, it is obvious that the problem of evaluation and control of industrial noise is rapidly being added to the burden of the industrial hygienist. Therefore, a Committee on Noise has been established by the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION in an attempt to keep the membership of the Association up-to-date on the rapid developments which are taking place.

On April 23, 1952 this Committee met for the first time at the Netherlands Plaza Hotel in Cincinnati during the annual meeting of the Association. Much of the discussion centered around the objectives which the Committee wished to accomplish. It was generally agreed at this meeting that at the present time the committee could be most helpful by the following activities:

1. Keeping the membership of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION abreast of new developments in the field of industrial noise.

2. Submitting a series of articles on noise for publication in the *Quarterly*.

3. Providing a program on industrial noise at the annual meeting of the Association to be held in Los Angeles, California in 1953.

4. Maintaining association with other scientific groups now actively engaged in this field.

5. Establishing a liaison with other groups, by sending copies of the *Quarterly* containing noise information to such interested groups as the American Medical Association, the American Standards Association, the National Safety Council, the American Academy of Ophthalmology and Otolaryngology and other interested groups.

It is reported that there are 18 research organizations devoting at least some time to the various aspects of the industrial

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noise problem. The list of organizations either actively engaged in, sponsoring, or interested in industrial noise research is impressive and a complete listing is beyond the scope of this report. However, the growing importance of the industrial noise problem and the diversity of interests surrounding it has prompted a number of groups to request the Industrial Hygiene Foundation to assume leadership in coordinating the many aspects of the problem.

Two meetings, including representatives of various interested groups, have already been held in Pittsburgh, Pennsylvania with the staff of the Industrial Hygiene Foundation in an attempt to establish basic principles under which a realistic program might be operated. Additional detailed plans are now being formulated which will doubtless receive general approval. It is hoped that this program, with the Industrial Hygiene Foundation as a coordinating group, can be established in the near future.

It may be of interest to the members of the Association to have a list of meetings during the next few months which are being devoted exclusively or in a large measure to the noise problem:

Third National Noise Abatement Symposium, Armour Research Foundation of the Illinois Institute of Technology, Chicago, Illinois, October 10, 1952.

Acoustical Society of America, San Diego, California, November 12-14, 1952.

American Industrial Hygiene Association, Thirteenth Annual Meeting, Statler Hotel, Los Angeles, California, April 21-23, 1953.

Acoustical Society of America, Atlantic City, New Jersey, May 7-9, 1953.

If there are any other open meetings not listed above your Committee would be eager to learn about them.

It is proposed to publish in the *Quarterly* from time to time, discussions of phases of the noise problem of interest to industrial hygienists. Since the major objectives of the Committee is to keep the Association membership informed, it would be most helpful if members would communicate to the Committee any ideas which they may have as to the kinds of information which would be most helpful.

—CHARLES R. WILLIAMS, Chairman
ALLEN D. BRANDT
LESTER V. CRALLEY
EDWARD C. MEITER
WALTER F. SCHOLTZ
JAMES H. STERNER
HERBERT T. WALWORTH

The National Noise Abatement Symposium

THE THIRD ANNUAL Noise Abatement Symposium will be held at Technology Center, Armour Research Foundation of Illinois Institute of Technology, Chicago 16, Illinois on October 10, 1952.

This year, the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION was invited to act as one of the sponsors of the Symposium. Other sponsors are Armour Research Foundation, The Acoustical Society of America, The Acoustical Materials Association, and the National Noise Abatement Council. The meeting is under the direction of a committee composed of the following: DANIEL B. CALLAWAY, Chairman, Armour Research Foundation; HALDON A. LEEDY, Armour Research Foundation, representing the Acoustical Society of America; HERBERT T. WALWORTH, Lumbermens Mutual Casualty Company, representing the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION; DUDLEY W. DAY, Burgess Manning Company, representing the National Noise Abatement Council; WILLIAM A. SPENCER, Armour Research Foundation, representing Armour Research Foundation: WALLACE WATERFALL, American Institute of Physics, representing The Acoustical Materials Association.

Program announcements are being forwarded to all members from the Executive Secretary's office.

On page 20 of the March, 1952, *Quarterly*, the second and third sentences of the fifth paragraph should read: "Two sounds of equal power when added together produce twice the power which is equivalent to $\sqrt{2}$ sound pressure. For example, the noise from two similar machines will produce a total sound pressure of $\sqrt{2}$ times the sound pressure for one machine."

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION

— News of the Local Sections —

Chicago Section

AT THE JUNE 4 meeting of the Chicago Section, DR. JOSEPH A. HUBATA discussed "The Use of Some New Drugs in the Industrial Medical Department." His talk included a survey of ACTH, Tryptar, and some of the anti-biotics. A color movie with sound, "Debridement with Tryptar," showing the treatment of infected wounds was also presented.

The highlights of the AIHA Annual Conference held in Cincinnati were reviewed.

During the annual business meeting of the Section, officers were elected for the year 1952-53. These include President, CHARLES W. WYMAN, Western Electric Company; President-Elect, HOWARD N. SCHULZ, Abbott Laboratories; and Secretary-Treasurer, WILLIAM T. MCCORMICK, Inland Steel Company. The following were elected directors for a three year term: LEON KIRSCHNER, Illinois Department of Labor; CHARLES S. LAUBLY, Lumbermens Mutual Casualty Company; GEORGE C. STOECKER, American Can Company; FLOYD A. VAN ATTA, National Safety Council.

Northern California Section

THE REGULAR meeting of the section was held at the Officers Club, Alameda Naval Air Station on May 20, 1952. The program included a paper, by LAWRENCE SCHMELZER, entitled "The X-ray Diffraction Method for Determining the Origin of Industrial Dusts," which was followed by a review of the Annual AIHA meeting in Cincinnati.

FRED R. INGRAM has resigned from the California State Health Department to accept the position of Chief Industrial Health Safety Engineer for the University of California's newly created Division of Occupational Health. This division will be responsible for on-the-job health of employees on all campuses. Eventually the staff will include, in addition to MR. INGRAM, a physician at the Berkeley headquarters and a chemist and an engineer at Berkeley and at Los Angeles to service campuses in the respective areas.

Tennessee Section

BREAKING the tradition in health meeting formats, the Tennessee Section of the AIHA, under the program leadership of its President-Elect, DR. GILBERT H. COLLINGS, JR., Chief of the Occupational Health Branch of the Tennessee Valley Authority, established a new device in professional forums. The Section's spring meeting took place Friday, March 14, 1952, in Sheffield, Alabama, which is located in the center of the Muscle Shoals area. The program was enthusiastically supported by the industries in the area.

The morning section, with W. H. CHILDRESS, American Zinc Company, as chairman, featured two addresses: "The Employee Health Program of the Tennessee Valley Authority" by DR. O. M. DERRYBERRY, Director of the Division of Health and Safety; and "Women in Industry" by DR. ANNA M. BAETJER, Assistant Professor, School of Hygiene and Public Health, Johns Hopkins University.

Field trips to the Reynolds Aluminum Company, Sheffield, Alabama and to the Wilson Dam and Hydroelectric Plant, Florence, Alabama, were conducted in the afternoon.

At the dinner meeting, a speech entitled, "Plant Management Looks at Industrial Health," was presented by J. T. FLAGG, The J. T. Flagg Knitting Company, Florence Alabama.

Following the dinner, a Panel Forum was held, in which a panel of seven experts answered queries from industry representatives.

Texas Section

THE Texas Section will hold its annual meeting in conjunction with the Fifth Annual Gulf Coast Regional Conference on Industrial Health to be held September 24-27 at the Rice Hotel, Houston, Texas. The section is a co-sponsor of this conference.

An important item of business at the meeting of the section will be concerned with the possibility of changing its name in view of the recent establishment of a North Texas Section.

THE LEAD INDUSTRIES Association announces the publication of a book entitled "Lead in Modern Industry," Lord Baltimore Press, Baltimore, 1952. Although this book is not concerned with the toxicology of lead or industrial health exposures, it contains much valuable information on the production and uses of lead and its compounds. Copies may be secured at $1.50 each from the Lead Industries Association at 420 Lexington Avenue, New York 17, New York.

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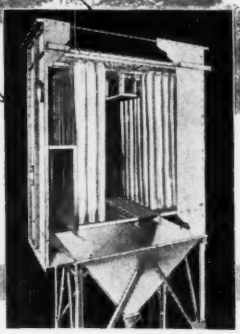

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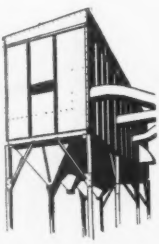

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